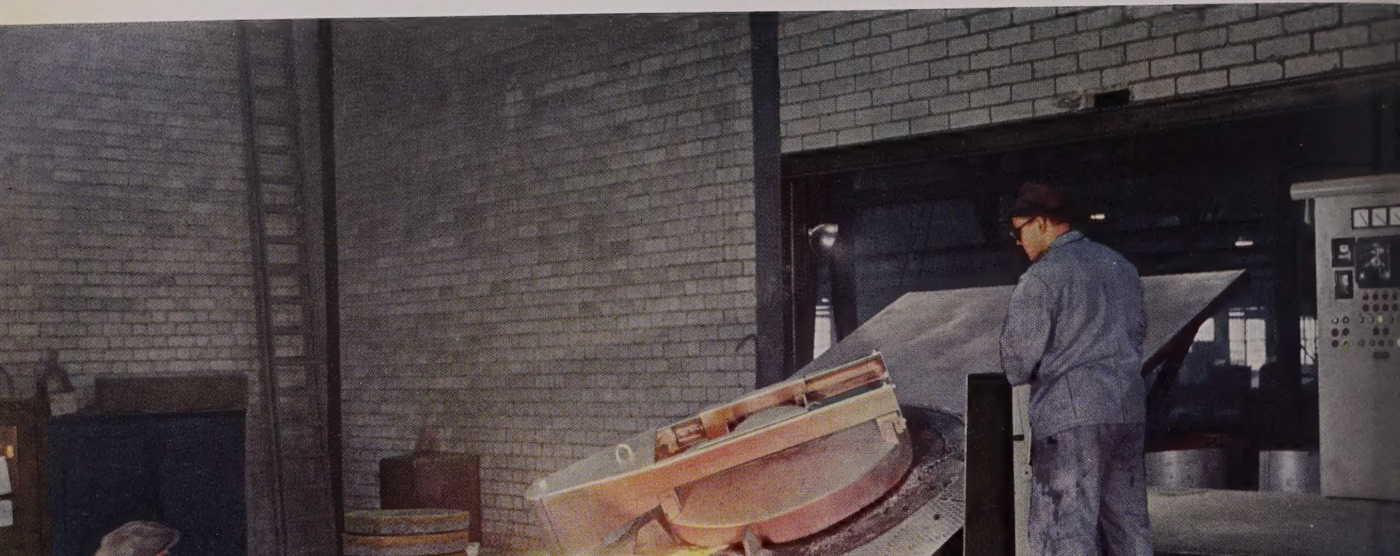
BROWN BOVERI REVIEW

RECEIVED
AUG 26 1960
INSTITUTE OF THE
ERONAUTICAL SCIENCES

The new standardized motor—well designed and rationally produced

BOVERI REV. VOL. 47 No. 3 p. 117–192 BADEN, MARCH 1960

Printed in Switzerland



Pouring a 6-t mains-frequency crucible induction furnace for grey cast iron

THE BROWN BOVERI REVIEW

ISSUED BY BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND)

VOL. 47 MARCH 1960 No. 3

The Brown Boveri Review appears monthly — Reproduction of articles or illustrations is permitted subject to full acknowledgement

CONTENTS:

Page

H. U. Würgler: New Induction Motors with Dimensions to IEC Recommendations . . . 119

A. Schenkel: Electrical Equipment for a Boring and Milling Machine with a Special Copying System . . 124

F. Glantschnig: Contactless Electronic Control of a Rapid-Reversing Drive . . . 131

W. Pohl and **H. R. Kunz**: Automatic Control of Cooling Beds . . . 136

F. von Burg: Coreless Mains-Frequency Crucible Induction Furnaces . . . 145

W. Brügger: Temperature Drop in Crucible Induction Furnaces During Supply Interruptions and Pouring . 159

K. Schärrer: Projection Welding, a Modern Method of Joining Metal Parts . . . 163

F. Gerspacher and **O. Waldvogel**: Resistance Welding Machines with Three-Phase Frequency-Changer . . . 180

Brief but interesting:

A. Grasset: A New Design of Pantograph Current Collector for Express Electric Trains . . . 185

NEW INDUCTION MOTORS WITH DIMENSIONS TO IEC RECOMMENDATIONS

621.313.333

Following a brief account of the present state of standardization achieved by IEC, the article describes the features of the new range of Brown Boveri squirrel-cage motors.

Standardization

In 1950 the technical committee of the IEC constituted the sub-committee B of group 2 "Rotating machines", whose task was to study international standardization of the dimensions of electric motors. The object of standardizing was to make motors of different makes interchangeable with one another, primarily as regards physical dimensions, without regard to the rating. It was agreed that the first motors to be standardized would be induction motors for 50 and 60 c/s, for low voltages up to 600 V, and with shaft centre heights up to about 300 mm.

The first results of this work appeared in IEC Publication No. 72, the first edition of which was issued in 1954, the second in 1956. The results were not entirely satisfactory because two quite different series of dimensions appeared, one in millimetres, the other in inches. The Indian national committee therefore made the proposal in 1956 that these two series should be unified. At the Stockholm conference in 1957 an agreement was reached; the outcome of this, which will now be described, was published as an IEC recommendation in part 1 of the third edition of publication No. 72, and appeared in 1959.

The IEC Recommendations

Standardization primarily concerns the principal dimensions of motors with feet (Fig. 1). Fifteen different values between 56 and 315 mm were laid down for the shaft centre height *H*. Allocated to each value of *H* there is a definite value of *C*, the distance between the centre-line of the nearest fixing hole in the foot and the shaft collar; a fixed value *A* for the distance between centres of the fixing holes

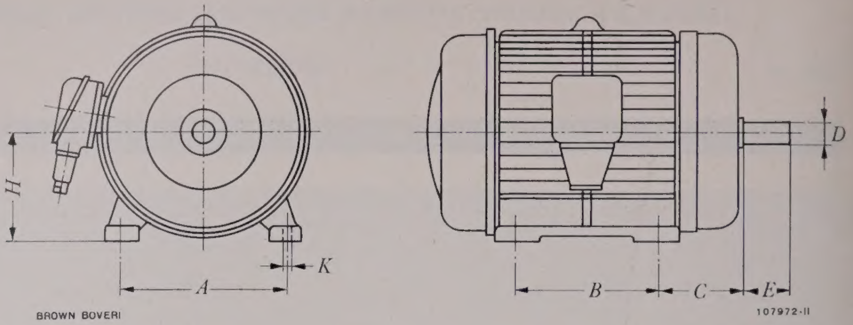


Fig. 1. – Symbols for the standardized dimensions of motors with feet

H = Shaft centre height; range 56–315 mm
C = Assigned value for the distance between the shaft collar and the centre of the near fixing holes
A = Distance between centres of fixing holes, perpendicular to axis of motor
B = Distance between centres of fixing holes, parallel to axis of motor
K = Maximum diameter of fixing holes
D = Diameter of shaft extension
E = Assigned length of shaft extension

on either side of the motor axis; different values of *B*, the distance between the centres of fixing holes parallel to the axis (*S*hort, *M*edium and *L*ong bodies); and the maximum diameter *K* of fixing holes in the feet. Stating the shaft centre height and the length of the body, e.g. 280 M, determines the assembly dimensions of a motor. Motors with equal shaft centre height *H* but different body length *B* only differ from one another in the positions of the fixing holes at the non-driving end.

For the shaft extensions recommended values were stated for the diameter *D* and length *E*. There is no connection between these and the other dimensions. For each shaft extension there is a maximum admissible torque, referred to steady, continuous operation. There are two sets of dimensions for the shaft extensions, one in millimetres, one in inches. The metric series is based on a long-standing ISO range, so that nothing basically new has been produced in this respect.

In the same publication IEC put forward a range of preferred ratings in kW and h.p., as follows:

kW	0·06	0·09	0·12	0·18	0·25	0·40	0·60
h.p.	1/12	1/8	1/6	1/4	1/3	1/2	3/4
kW	0·8	1·1	1·5	2·2	3·7	5·5	7.4
h.p.	1	1·5	2	3	5	7·5	10
kW	11	15	18·5	22	30	37	45
h.p.	15	20	25	30	40	50	60
kW	55	75	90	110			
h.p.	75	100	125	150			

However, IEC make no connection between the rating of a motor and its dimensions.

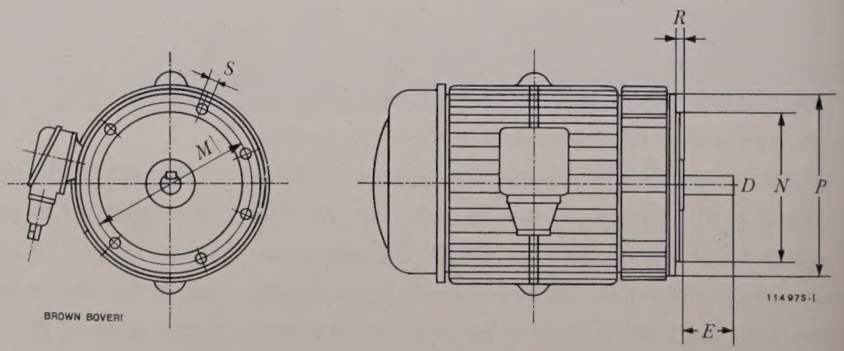


Fig. 2. – Symbols for standardized dimensions of flanged motors

M = Diameter of circle through centres of bolt-holes
N = Diameter of centering circle
P = Outside diameter of flange
S = Diameter of bolt-holes
D = Diameter of shaft extension
E = Assigned length of shaft extension
R = Distance between bearing surface of flange and shaft collar

In a second part of publication No. 72 recommendations will be made regarding the dimensions of flanges for flanged motors (Fig. 2). As for the shaft extensions, there are two sets of dimensions for the flanges in millimetres and inches. The metric sizes are based on existing ISO standards, the inch sizes on NEMA standards. The size of a flange is defined by the diameter of the circle through the centres of the bolt-holes. Hence an F 300 motor is a flanged motor with fixing holes on a circle 300 mm in diameter (*M*). The recommendations made regarding shaft extensions and ratings of motors with feet also apply to flanged motors.

Further Trends

The IEC recommendations make no attempt whatsoever to establish a relationship between the size of a motor on the one hand, and the rating and shaft extension on the other. Nevertheless, in some countries efforts are being made to carry standardization a stage further by allocating a definite rating to each size. This would naturally simplify the interchangeability of different makes of motors; but if carried too far, standardization can hamper progress, for example, by preventing more than the standardized output being obtained from a certain size of motor. Of course, this strict assignment can only apply to one type of motor, e.g. totally enclosed squirrel-cage, so that interchangeability with other types of motors is not necessarily possible. Brown Boveri are watching this development with great interest.

Standardization of Brown Boveri Motors and Type Designation

For new designs of induction motors, the Company intends to adhere to the IEC recommendations described above and incorporate the official size designation of motors with feet in the type designation. Thus, for instance, type MU 132 M 4 is a totally enclosed fan-cooled three-phase squirrel-cage motor, size 132 M, with four poles.

Since the flanged motors use the same parts, except for the body having no feet but the flanged end-shield at the driving end, the type designation follows the same rules as motors with feet; hence type MUFA 132 M 4, is a motor of the same type as previously described with feet, except that it is fitted with a type A flange to VSM standards,[1] which in turn corresponds to the IEC designation F 215. The corresponding motor with feet and flange—the latter normally VSM type B—is designated type MUPB 132 M 4.

Brown Boveri Standard Induction Motors

Standardization of the Company's motors on the lines suggested by the IEC recommendations has begun with the totally enclosed fan-cooled (TEFC) squirrel-cage motors. One of the reasons for beginning the programme of redesigning with this type of motor is the increasing demand for totally enclosed motors for the smaller outputs, since the growth of system capacities with interconnection permits larger squirrel-cage motors to be started direct-on-line, thereby tending to eliminate the more expensive slip-ring motors. Another reason is the growing number of customers who appreciate the reduction in maintenance with a totally enclosed motor.

The new Brown Boveri TEFC squirrel-cage motors are divided into two categories, namely the small motors with shaft centre heights up to 132 mm and ratings up to 7·5 kW (10 h.p.) at 1500 rev/min, and the larger motors with shaft centre heights of 160 to 315 mm and ratings up to 130 kW (175 h.p.) at 1500 rev/min. Naturally a feature common to both categories is that they conform to IEC recommendations, both as regards the dimensions and the standardized rating graduation for four-pole 50-c/s motors. With different numbers of poles and other frequencies, as well as when a lower temperature rise is stipulated, the rating differs sometimes from

---

[1] VSM = Verein Schweizerischer Maschinenindustrieller = Swiss Society of Machinery Manufacturers.

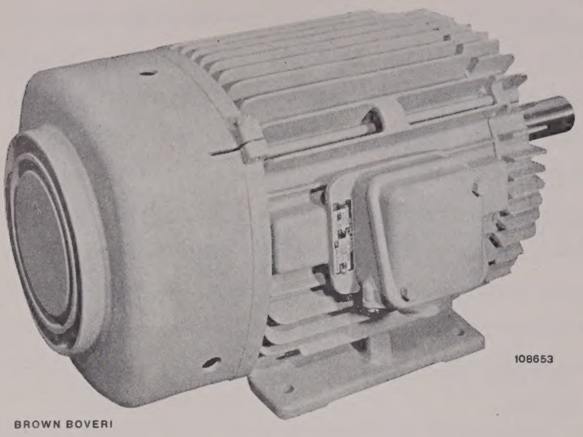


Fig. 3. – Small motor with feet

the standardized figure. The body of all sizes, even the smallest, is provided with ribs to increase the surface area for cooling. As previously, they are provided with ball bearings and permanent grease packing, with facility for lubrication through a nipple, fitted as a standard feature to all motors. The normal winding is of varnished wire, with insulation conforming to class E of IEC publication No. 85 (1957).

Small Motors

The smaller motors, up to the previously mentioned rating limit of 7·5 kW (10 h.p.) at 1500 rev per min, will in future only be manufactured in one form, i.e. as totally enclosed fan-cooled (TEFC). Well-planned design together with rational production has made it possible for the works cost of this motor to be lowered to such an extent that there is no justification for manufacturing a parallel series of drip-proof motors, because there would be no noticeable difference in price. The TEFC motors require far less attention, therefore to reduce maintenance costs customers have for a long time tended to employ exclusively totally enclosed motors for the smaller ratings.

In order to make better use of the space, the conventional round cross-section has been dropped for the small motors (Fig. 3) and, by increasing the length of some of the ribs, the cooling of the frame has been improved. In addition to being manufactured with feet, the small squirrel-cage motors are also available with flange, or with feet and flange, in which case the flange has either untapped boltholes (VSM type A) or tapped holes (VSM type B) as shown in Fig. 4 and 5.

As previously, the frame and end-shields of the smallest types are made of steel-reinforced light metal with the feet cast in. This design has proved so successful that it is being employed for even higher ratings than before, namely up to 0·75 kW (1 h.p.) at 1500 rev/min. For higher ratings the motors have a cast-iron frame and end-shields.

Squirrel-Cage Motors for Higher Ratings

The design of these motors differs slightly from that of the smaller motors. They have a circular cross-section and a cast reinforcing ring round the

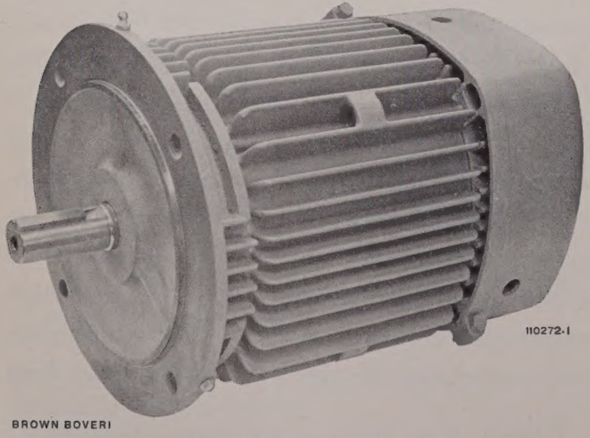


Fig. 4. – Small motor with type A flange

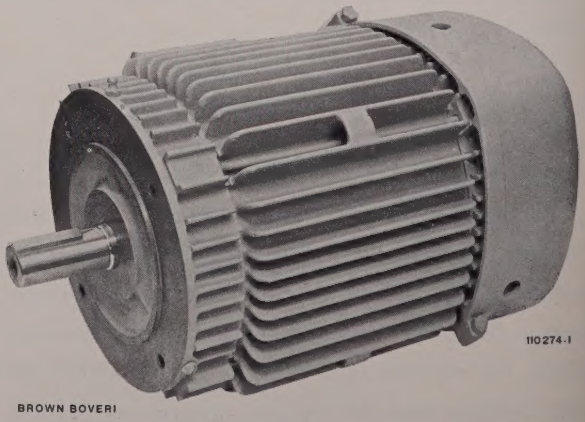


Fig. 5.– Small motor with type B flange

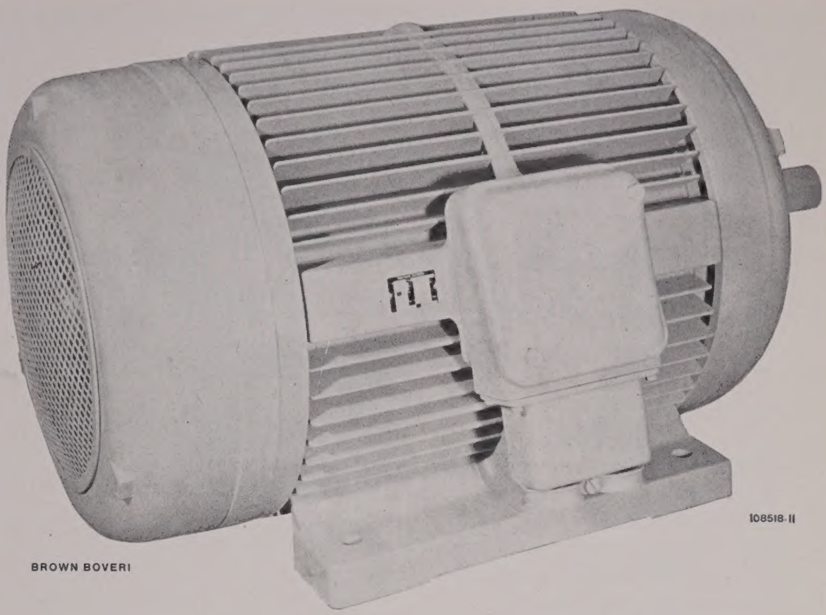


Fig. 6. – Squirrel-cage motor for higher ratings

middle, from which the motor can also be suspended at the top (see Fig. 6). These motors are also obtainable with feet, with flange, or with feet and flange (VSM type A flange with untapped bolt-holes). The normal rotor is suitable for direct-on-line or star-delta starting. For the higher ratings the motors are supplied with a double-cage rotor to produce a higher initial torque with star-delta start.

For this higher range of ratings of the new TEFC motors, i.e. above 7·5 kW (10 h.p.) at 1500 rev/min, the Company will continue to develop slip-ring motors with the same enclosure, also slip-ring and squirrel-cage drip-proof motors. The modification of existing designs to conform to IEC recommendations will in this case take place progressively.

The standardization of induction motors under the auspices of IEC is a world-wide development and assures the purchaser many inherent advantages. The introduction of a complete series of TEFC squirrel-cage motors is Brown Boveri's first step in following this development.

(KME) H. U. WÜRGLER

ELECTRICAL EQUIPMENT FOR A BORING AND MILLING MACHINE WITH A SPECIAL COPYING SYSTEM

621.954 - 83

A short time ago a special kind of boring and milling machine was taken into service in the workshops of Andritz AG., Graz, Austria, where it is employed for machining large Kaplan runners by copying a model. Not only is the design of the machine itself interesting, the electrical equipment also includes some noteworthy features, which are described in the present article.

Some Stipulations Regarding the Mechanical and Electrical Equipment

THE PURCHASE of a large machine tool is a very expensive business and is only an economical proposition if the machine is constantly kept busy. Therefore, for the engineering industry, it is almost a matter of course for such machines to be designed to be very versatile and thus able to work almost incessantly. This category of machine tools includes large boring and milling machines which are noted for their ability to be employed for different machining processes.

The above considerations governed the purchase by Andritz AG. of Graz of the boring and milling machine which will now be described (Fig. 1). For this machine, manufactured by Schiess AG., Dusseldorf, the customers made stipulations exceeding those for normal designs. Thus, for instance, one stipulation under discussion was whether the machine could produce Kaplan runners with sufficient accuracy by an automatic copying system and, at the same time, be suitable for ordinary boring and milling work. When the question of a suitable copying system was studied, it was proved that only a purely electrical system completely conformed to the mechanical design of the machine.

Electrical Equipment for Normal Machine Functions

The main drive is a pole-changing three-phase squirrel-cage motor rated 33 and 44 kW at speeds of 725 and 1440 rev/min, respectively, which drives the cutting spindle through gearing. This motor is always switched on at its lower speed in order to avoid inadmissible current peaks. For high-speed braking d.c. is used, supplied by a separate generator, which is simultaneously coupled to a second generator providing the 24-V d.c. supply for the magnetic couplings. A system of Ipsotherm protection incorporated in the main motor sets off an alarm when an overload occurs and trips the main switch if this overload persists.

In order to keep the weight of the pivoted headstock as light as possible, the feed motor (speed range 100–3300 rev/min) with its gearing and magnetic coupling was fitted at the base of the pillar (Fig. 2), from which position the movements of the headstock and milling spindle are transmitted by a vertical shaft. With one speed change in the feed rate, obtained with an automatically operated double magnetic coupling, it is possible to obtain a feed range of about 1 : 1000 without any interruption. The headstock, cutting sleeve, slides and pillars are locked by means of three-phase stop motors.

The control gear is divided into two parts; one in a fixed cabinet (Fig. 3) containing the control gear for the main motor, the star-delta switch for the feed converter, as well as contactors and fuses for the auxiliary a.c. drives; the other part is

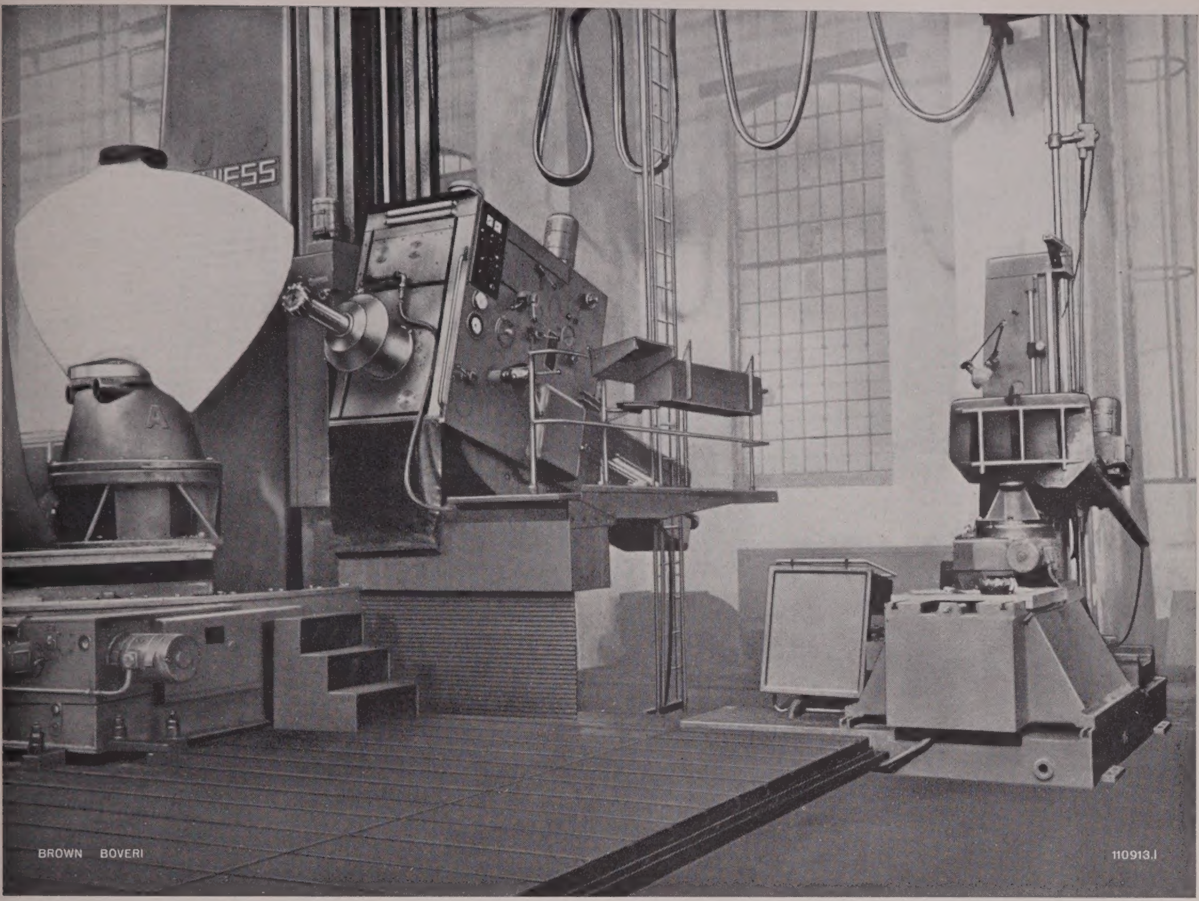


Fig. 1. – Boring and milling machine with pivoted headstock and separate turntable

It can be used for normal milling and boring or, in conjunction with copying control and a model machine, for automatic machining of blades for Kaplan runners and similar objects.

The electrical equipment includes:

Pole-changing main motor 33/44 kW at 725/1400 rev/min,

Ward-Leonard drive rated 18·5 kW at 3300 rev/min for the feed of the headstock, pillar and boring bar; also several auxiliary three-phase motors, totalling 40 kW, together with all the control gear.

For copying, the following are also incorporated:

Four Ward-Leonard drives, each 1·1–2 kW at 1000 rev/min, for the various movements, in conjunction with five selsyns each producing 0·1 mkg for the coordination of the main and model machines; also the copying system with tangential detector for adjustment of the cutting angle.

on a frame mounted in the pillar of the machine (Fig. 4) and comprises the equipment controlling the Ward-Leonard feed circuit and the magnetic clutches.

When working normally the machine can be controlled from two pendant units, one of which is mounted in the headstock, the other being portable. The front panels of these units are equipped with a schematic diagram of the machine, which greatly simplifies operation.

Tasks of the Electric Copying Control System

Machining the surfaces of Kaplan turbine runners and similar workpieces, e.g. matrices, has always been a delicate and costly process, because it involves the production of three-dimensional curves which cannot be obtained with rotary or uniformly oscillating movements. Copying systems were devised a long time ago for this machining process, in

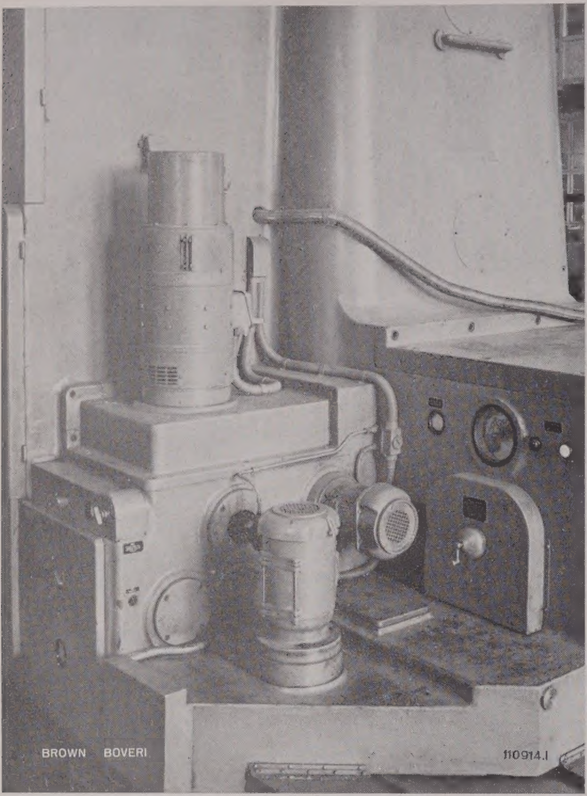


Fig. 2. – Gear-box for the feed motions, mounted on the pillar of the boring and milling machine, with a variable-speed Ward-Leonard d.c. motor rated 18·8 kW at 3300 rev/min, for the movement of the headstock, pillar and boring bar

At the bottom is the stop motor rated 3 kW for locking the pillar; on the right the oil-pump motor for the gear-box lubrication.

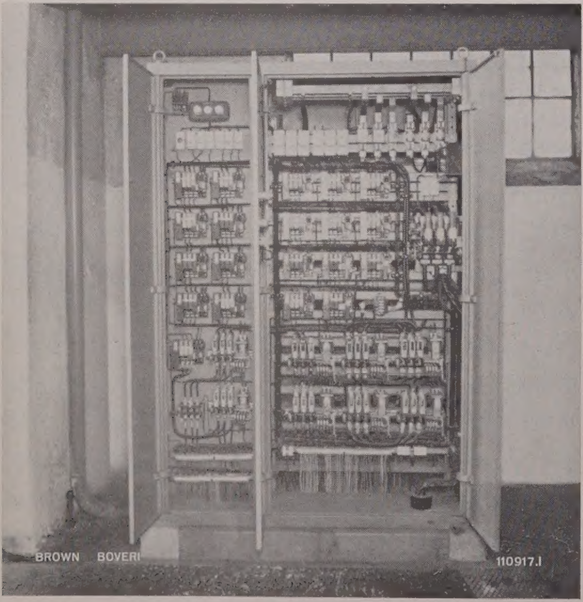


Fig. 3. – Fixed cabinet containing the control gear for the main motor, feed converter and various three-phase auxiliaries

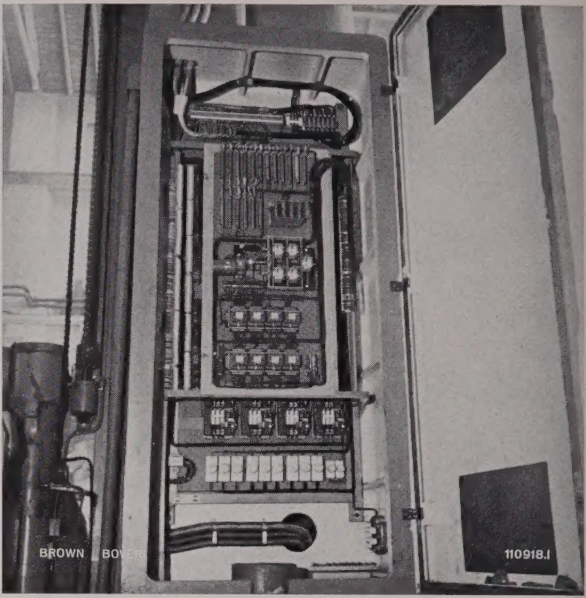


Fig. 4. – Control gear mounted on a frame in the pillar of the boring and milling machine, with elements for the Ward-Leonard feed control, for the three-phase auxiliary motors on the headstock, and for the magnetic couplings

order to reduce the costs and attain sufficient accuracy. A particular difficulty in solving this problem is the need to keep a cutting tool of large diameter at a predetermined angle to the surface being machined. In the copying system which will now be described, this problem was solved very elegantly.[1]

As can be seen from Fig. 1, a special model machine is used which, in effect, is a scale model of the main machine and with its detector follows every movement of the main machine. The ratio of the two movements can be varied between 1:1 and 1:6 by interchanging wheels, thereby enabling workpieces of the same shape to be machined to any size with the same pattern. In addition to the model machine, a turntable and model table are required to hold the workpiece and the pattern and, in conjunction with the pivoted headstock, to bring the workpiece and tool to the correct cutting angle when milling. If the manner in which the process has to be performed is considered, taking the example of

---

[1] L. Büschgens: Selbsttätige Schnittwinkelnachstellung beim Fräsen von Kaplan-Turbinenschaufeln. VDI-Nachrichten 1958, No. 22, p. 1.

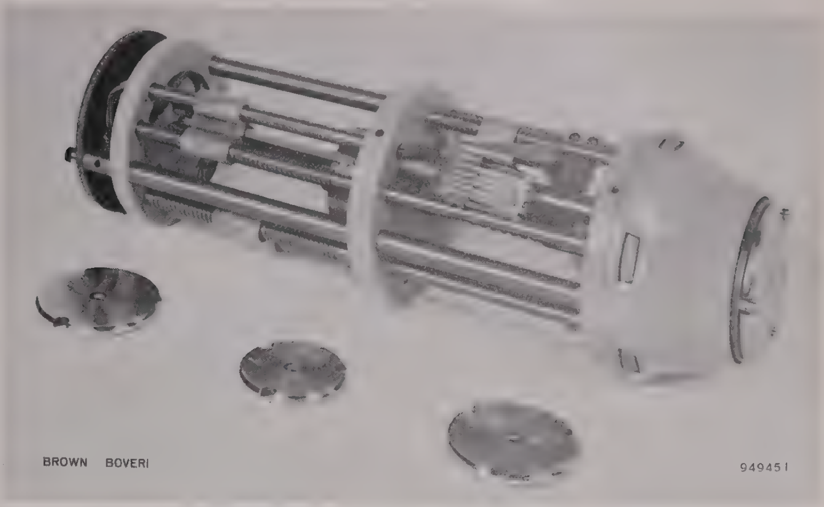


Fig. 5. – Bi-system contact detector for depth and tangential detection on a model used for machining the blades of Kaplan runners

The detector discs (at the front) are inserted according to the size of the cutter and the copying ratio, while the adjustable feeler pins are used for maintaining a preset cutting angle, including inclination.

a Kaplan runner, which is curved horizontally and vertically, it is apparent that the following motions have to be controlled:

1st coordinate = pillar (master) feed to "left or right"
2nd coordinate = cutting spindle "forwards and reverse" and table rotation "forwards and reverse" (projection of tool)
3rd coordinate = headstock "up and down" (pivoting) and "raise and lower" (height of tool)

Thus a total of five reversing motions in three coordinates have to be analysed by the electric detector, in addition to the shape and cutting position of the tool.

The Special Electrical Detector

Since no suitable detector was available on the market, one had to be developed. This three-dimensional contact detector possesses two independent detecting systems (Fig. 5), one in the centre for controlling the spindle feed, and one on the outside for tangential detection to set the angle of the cutting tool. The inner detector head contains an interchangeable disc which corresponds to the cutter in size and shape—according to the copying ratio of pattern to workpiece. The outer detector system comprises three feeler pins, whose heights are separately adjustable from outside, whose distance apart can be varied according to the size of the cutter and whose difference in height governs the inclination of the tool. Both detector systems actuate suitably designed contact systems, whose sensitivity can be set from outside by knobs operating levers.

The Electrical Transmission System Main Machine – Model Machine

As mentioned earlier, the machine has a variable-speed feed motor, from which the movements of the pillar, headstock and cutting spindle projection are taken off through magnetic couplings. The rotary movements of the headstock and turntable are produced by ordinary three-phase motors also in conjunction with appropriate magnetic couplings. Strictly speaking, the electrically operated elements for the copying control are thus complete. But since mechanical connecting elements for the simultaneous movement of the main and model machines would have been extremely complicated and therefore expensive, it was decided that single-phase selsyns would be preferable (Fig. 6). An investigation of this point gave the following result.

Only about $^{1}/_{5}$ to $^{1}/_{4}$ of the torque of the couplings was utilized when copying because they were

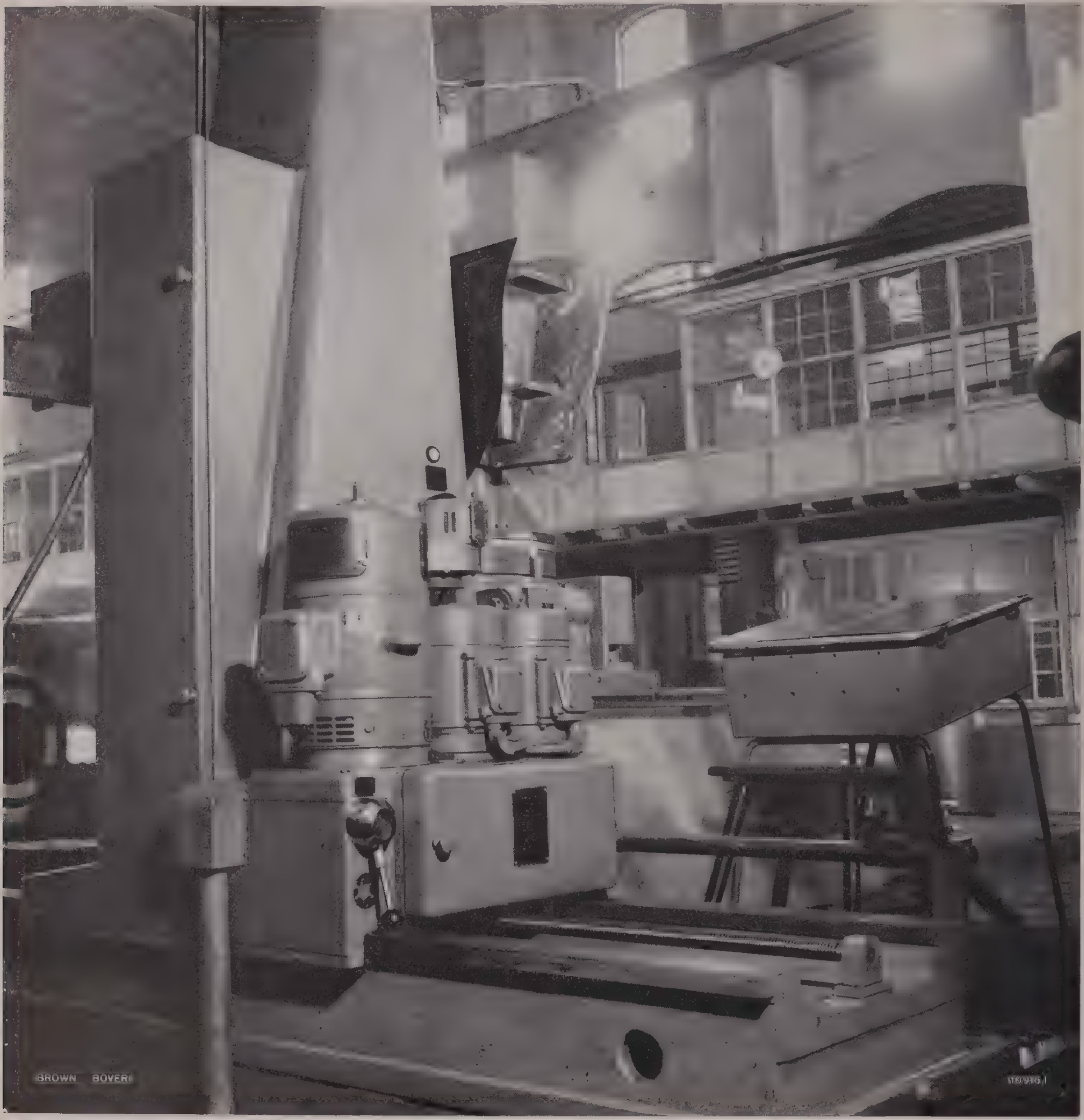


Fig. 6. – Single-phase receiver motor of the selsyn on the pillar of the model machine, for the movement of the pillar, headstock and boring spindle in synchronism with the main machine

designed for normal operating conditions. According to the measurements which were taken, the characteristic of the coupling is such that, on expiry of the energizing period, the full dynamic torque is transmitted almost at once, in other words the load is applied abruptly to the transmitter of the selsyn, which consequently loses its synchronization. On account of this, small Ward-Leonard d.c. motors replace the couplings for copying. With these machines the forces produced by acceleration and retardation are precisely mastered and the adjustment speed for copying is exactly obtained (Fig. 7). Experience in practice has proved that this method was correct.

Principle of the Copying System

The system of copying used for milling will now be briefly described. To begin with, the main and model machines have to be brought electrically into their predetermined starting positions, the one independent of the other. For positioning the main machine and the turntable the motors provided are used in conjunction with the magnetic couplings, while for the pattern the selsyn receivers are connected as three-phase motors. Then the single-phase selsyns are switched on, thereby correlating the movements of the main and model machines. For the continued high-speed motions of the two machines the d.c. motors of the main machine are used from this point on, the magnetic coupling being blocked. By means of push-buttons the cutter is guided at the high traversing speed to the starting point for indexing and the command given for "copying". The cutter starts to rotate at the preselected speed; at the same time the feed motion of the cutting spindle commences automatically, and with it the movement of the detector arm. If the detector disc touches the template, the master feed (pillar motion) is switched on in the preselected direction. The three outer pins of the detector ensure that the head is approximately perpendicular to the surface of the model, and that the cutter bears the same relationship to the machining surface, by actuating the pivoting movements of the headstock and the turntable. When the pressure on the detector reaches a certain magnitude the forward motions of the milling spindle and the detector are interrupted. If the pressure continues to increase, the reverse motion is automatically switched on until the pressure on the detector is normal again. The automatic adjustment of the cutting angle, as already mentioned, is performed with the aid of the detector pins which actuate the associated contacts through a linkage system and actuate the pivoting movement of either the headstock or the turntable, as required. The adjustment of the inclination of the cutter is effected by a difference in height of at least one of the detector pins. In view of the inclination of the cutter, machining is only performed in one direction, at the end of a pass the detector and cutting spindle are withdrawn, the main and model machine returning simultaneously at the fast rate back to the beginning. Thus the preset synchronization is

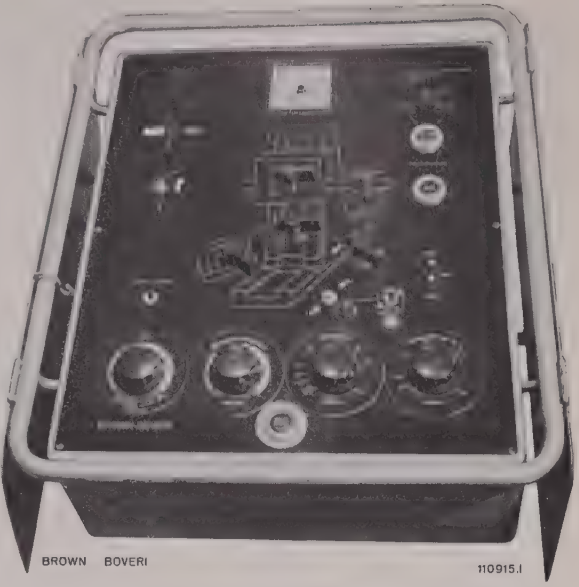
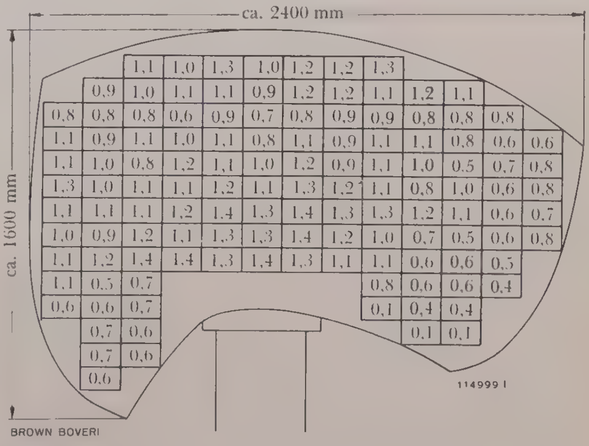


Fig. 7. – Copying controls of the boring and milling machine

The rotary switches on the diagram of the model are used for setting up the model by means of the selsyn receivers, which in this case act as three-phase motors. The copying speeds of the various movements can be adjusted accurately by means of the potentiometer at the bottom of the panel.



		1,1	1,0	1,3	1,0	1,2	1,2	1,3				
	0,9	1,0	1,1	1,1	0,9	1,2	1,2	1,1	1,2	1,1		
0,8	0,8	0,8	0,6	0,9	0,7	0,8	0,9	0,9	0,8	0,8	0,8	
1,1	0,9	1,1	1,0	1,1	0,8	1,1	0,9	1,1	1,1	0,8	0,6	0.6
1,1	1,0	0,8	1,2	1,1	1,0	1,2	0,9	1,1	1,0	0.5	0,7	0,8
1,3	1,0	1,1	1,1	1,2	1,1	1,3	1,2	1,1	0,8	1,0	0,6	0,8
1,1	1,1	1,1	1,2	1,4	1,3	1,4	1,3	1,3	1,2	1,1	0,6	0,7
1,0	0,9	1,2	1,1	1,3	1,3	1,4	1,2	1,0	0,7	0,5	0,6	0,8
1,1	1,2	1,4	1,4	1,3	1,4	1,3	1,1	1,1	0,6	0,6	0,5	
1,1	0,5	0,7						0,8	0,6	0,6	0,4	
0,6	0,6	0,7						0,1	0,4	0,4		
	0,7	0,6							0,1	0,1		
	0,7	0,6										
	0,6											

Fig. 8. – Check measurements on a blade 2·4 m wide machined by the copying process with a ratio of 1:3·75 between pattern and workpiece

As these figures show, the maximum error in shape is about 1·3 mm, with a local inaccuracy of 0·1 mm which, according to the specialists, is very good.

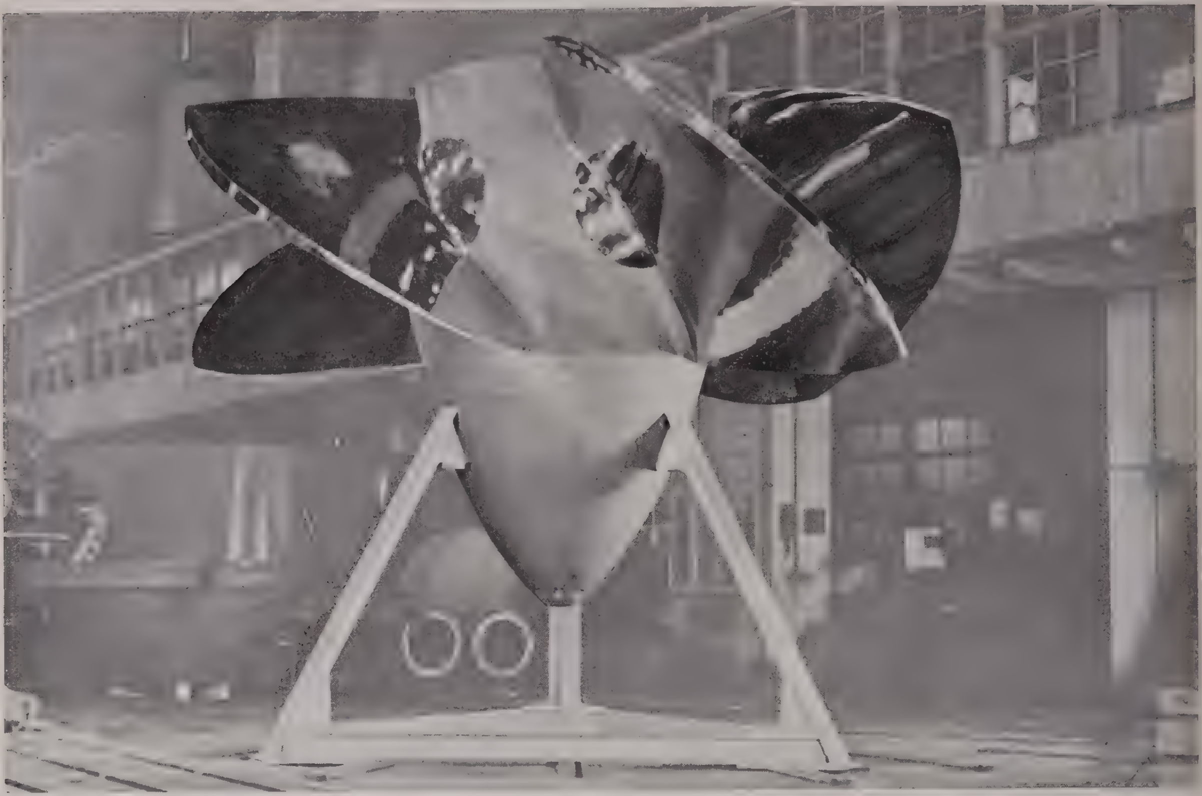


Fig. 9. – Blades of Kaplan runners like the one illustrated are machined on the Schiess copying milling machine installed in the works of Andritz AG., in Graz (Austria)

maintained. A special linkage whose point of engagement is on the detector head ensures that the cutter traverses in a straight line; it is also used for adjustment of the traverse. Special ancillary devices for the detector allow the copying process to be used for the roots of the blades and for the outline. Protection against breakage is afforded by an emergency contact in the detector which picks up when the pressure on the detector plate becomes excessive, and switches off the master feed, or the entire detector control if need be. By reversing the direction of the master feed an image surface can be machined.

A point which remains to be mentioned is that the machine is not designed solely for machining Kaplan blades by copying, but can also be used for other workpieces, such as matrices for the automobile industry.

This machine has now been in service for nine months with hardly an interruption, with three shifts a day. It has been used to machine a large number of blades, the accuracy obtained being in every case better than that stipulated by the purchaser. Thus, for instance, the local copying accuracy between the pattern and workpiece is about 0·1 mm while the shaping accuracy (Fig. 8) of a blade about 2·4 m wide with a copying ratio of 1:3·75 is in the region of 1·3 mm which, according to the specialists, is extremely good. This excellent result is not only due to the first-class mechanical design of the machine, but also to the impeccable operation of the copying system and the remainder of the electrical equipment (see also Fig. 9).

(KME) A. SCHENKEL

CONTACTLESS ELECTRONIC CONTROL OF A RAPID-REVERSING DRIVE

621.9-83:621.38

Following a brief review of the characteristic features and applications of the classical Ward-Leonard rapid-reversing drive, the present article gives an account of the design, principle and properties of a more modern reversing drive. The continuously repeated action of this drive, which is primarily intended for planing and broaching machines, is electronically controlled, without any contacts, by logic circuits employing transistors. Special mention is made of the position indicator which likewise functions without contacts.

The Normal Rapid-Reversing Drive

THE WARD-LEONARD drive, which is now the classical system for planing machines, was already being used over 30 years ago. Its salient features, such as the stepless speed variation, almost loss-free dissipation of braking energy (regeneration), its high short-time overload capacity, and its mechanical robustness and reliability, predestined it for this task.

The original direct method of reversing the drive by varying the field of the shunt-wound d.c. motor and the later system of reversing the field of the Ward-Leonard generator, did not provide a completely satisfactory reversal characteristic. In both cases large contactors were required, and the control gear for starting and braking were rather cumbersome owing to the power involved.

Therefore, it was not long before Brown Boveri replaced these methods by their own rapid-reversing drive, the main feature of which was the intermediate exciter with several control windings. For nearly 30 years this circuit has remained practically unchanged and during that time has given excellent results. It has not only been employed for planing machines, but also for other machines requiring regular reversal. The point of reversal is usually marked by adjustable dogs on the table which strike reversing switches. Acting through relays the latter reverse the separate excitation winding of the intermediate exciter, and thus reverse the drive. But progressive development brought faster and more efficient machines and thus more frequent reversal. The reversing switches and relays were accordingly exposed to increasingly severe stresses, and it is on these components that the drive mainly relies for dependable operation.

A further feature of the normal drive is the independence of the point of reversal with regard to the speed. Since the speed can be varied during operation, great care must be taken when planing up to a shoulder with a very short run-out. In contrast to planers, where this property could be tolerated under normal conditions, a constant reversal point is essential for broaching machines, especially when used for cutting gears. To comply with this, a variety of solutions have been realized,[1] with which the drive is subjected to preliminary retardation at a time varying with the speed of the motor, by a preceding switch, so that the actual reversing switch was always approached at the about same speed. By careful adjustment, the constancy of the reversing point could be assured to within a few millimetres throughout the entire speed range. But such solutions require twice as many switches and relays, thereby doubling the number of potential sources of trouble.

---

[1] M. STEINEBRUNNER and A. SCHENKEL: Ward-Leonard Drives for Large Machine Tools. Brown Boveri Rev. 1956, Vol. 43, No. 5, p. 136–46.

Contactless Reversing Drive

The ability to use modern electronic control and switching systems employing semiconductors made possible the fulfilment of the severest conditions. The well-tried Ward-Leonard drive with intermediate exciter can now be combined with an electronic controller and a reference input and programming unit composed of transistor circuits to obtain the following properties:

Independent preselection of the cutting and return speeds;

The speed is unaffected by fluctuation of the load or temperature;

Linear and accurate relationship between the speed and the reference (setting) potentiometer;

The acceleration and braking torque is adjustable and kept constant by limitation;

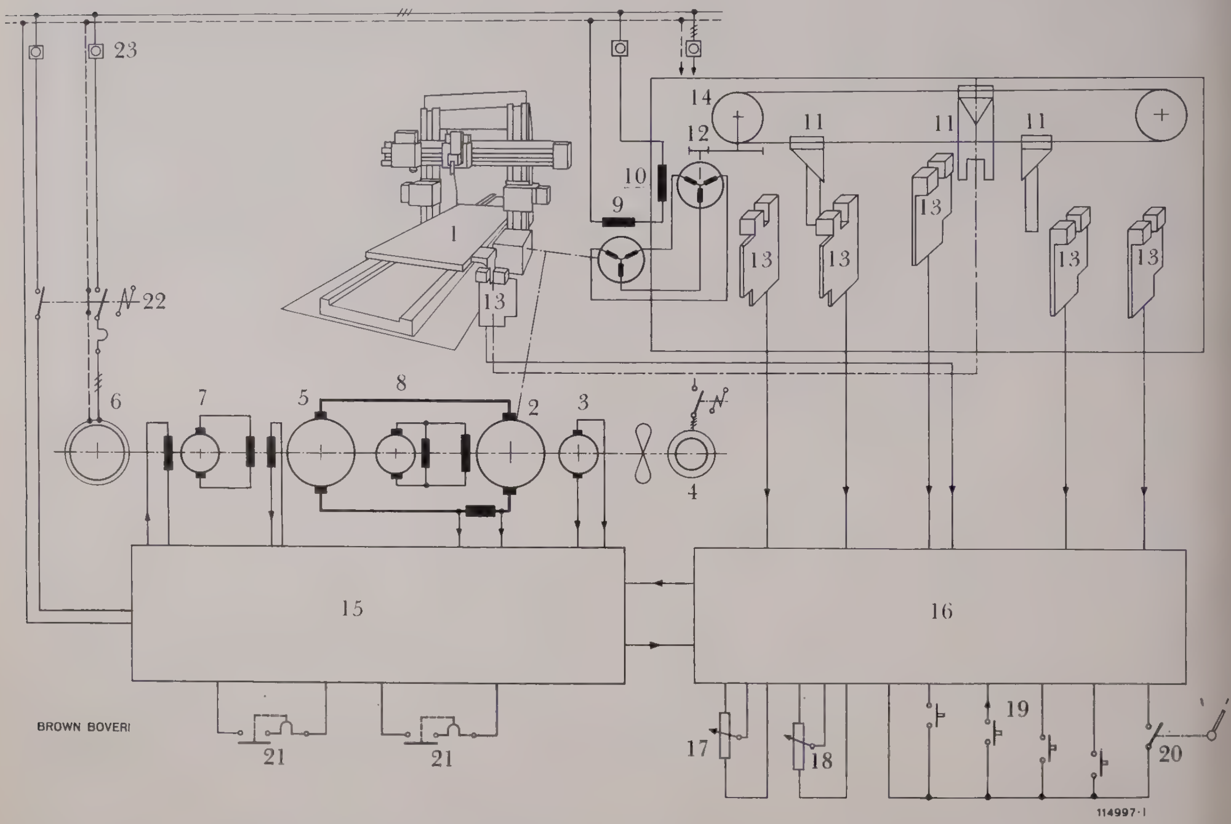
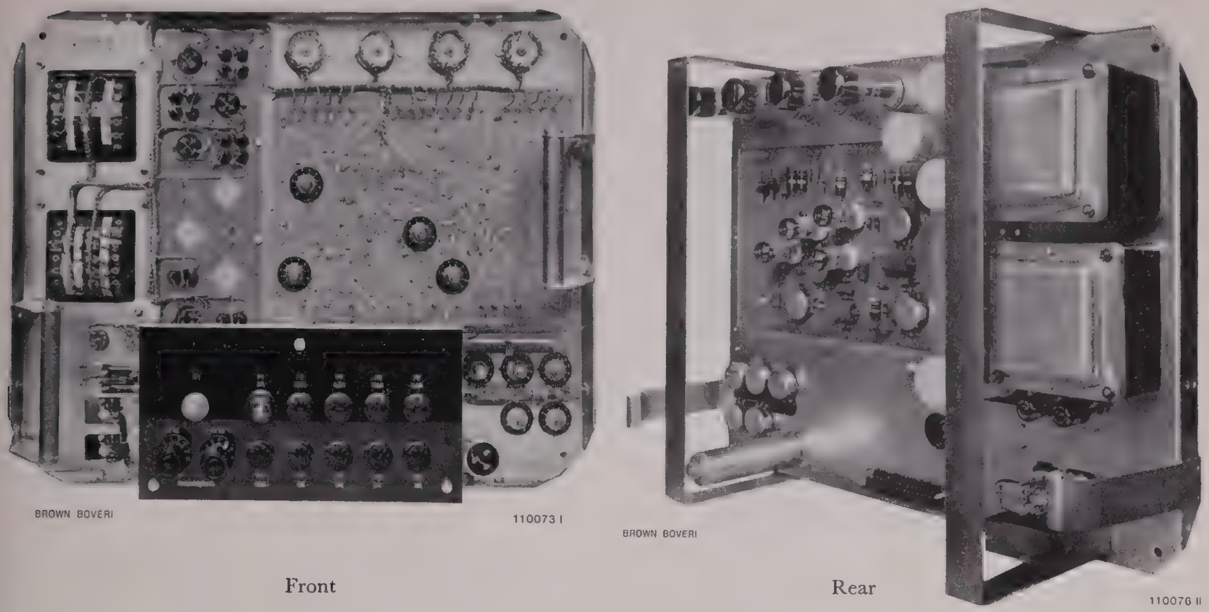


Fig. 1. – Block diagram of the contactless electronic control of a rapid-reversing drive

The outlined elements are combined in a common control desk.

1 = Planing machine
2 = Drive motor
3 = Tacho-generator
4 = Axial fan
5 = Ward-Leonard generator
6 = Three-phase motor
7 = Intermediate exciter
8 = Main exciter
9 = Selsyn transmitter
10 = Selsyn receiver
11 = Pointer
12 = Reduction gear
13 = Oscillator position indicator
14 = System for adjusting pointers on the desk
15 = Electronic control amplifier
16 = Reference input unit
17 = Potentiometer for setting cutting speed
18 = Potentiometer for setting return speed
19 = Push-buttons for manual commands
20 = Setting-up switch
21 = Thermal overload protecting switch
22 = Converter contactor
23 = Fuses



Front

Rear

Fig. 2. – Electronic control amplifier

This unit, which acts as a d.c. push-pull amplifier with a proportional-integral-derivative action, extends the scope of the ordinary Ward-Leonard drive and enables it to fulfil the requirements imposed on a variable-speed drive.

The main design features of this unit are:

Neat layout on a plug-in chassis

Adjustment to the particular operating conditions by potentiometers,

Use of long-life industrial tubes and silicon diodes,

Control amplifier employs printed circuits,

All points in the circuit are easily accessible for inspection and servicing, even when plugged in during operation.

The reversing point is constant, regardless of the set speed;

The travel of the table can be preset on the control desk;

The table or broaching tool can be controlled according to a set programme, e.g. stopping only in a defined end position, emission of control pulses for feed, tool lifting and interlocks;

Complete freedom from contacts for the normal working sequence, therefore no wear.

In a simplified circuit diagram Fig. 1 illustrates the arrangement and principle of the drive. The drive motor 2 is a quick-starting motor, i.e. a d.c. machine specially developed for reversing drives, with a very small moment of inertia relative to the torque which can be imparted. In addition to the separately driven fan 4, the motor is equipped with a tacho-generator 3 to measure the actual speed. The Ward-Leonard generator 5 feeding the drive motor is excited by the intermediate exciter 7. The excitation field of the latter, which acts primarily as a power amplifier, is fed direct from the control amplifier. To stabilize the control circuit, a voltage proportional to the change in flux of the generator field is fed back to the control amplifier with the aid of a special winding.

A measure of the desired table speed, i.e. the motor speed which produces it, is provided by a stabilized voltage whose magnitude can be preset on potentiometers 17 and 18. By means of the reference input unit 16, which will be described in an article to be published later, this voltage is applied to the input of the control amplifier with a polarity corresponding to the direction of rotation. This

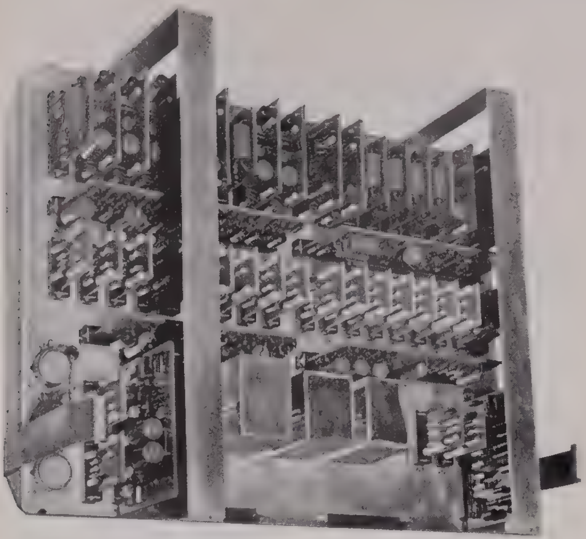


Fig. 3. – Reference input unit

This transistorized unit combines digital and analogue principles. It is the actual "brain" of the whole control system. The consistent construction from plug-in elements employing printed circuits meets the requirements for complete interchangeability of like elements, and enables a fault to be located by exchanging sub-units.

voltage is compared with that coming from the tacho-generator, the difference, after suitable amplification, becoming the excitation voltage of the intermediate exciter. The control system tends to reduce the difference between desired and actual values and therefore attains a state of equilibrium at the moment when the difference voltage is just sufficient for the control amplifier to produce a sufficiently high current output (for the intermediate exciter) that, at the resultant speed, the sum of difference and tacho-generator voltages equals the desired (reference) voltage. The polarity of the output current of the control amplifier corresponds to that of the input voltage. Thus if the polarity of the desired voltage is changed by the reference input unit, the intermediate exciter also causes the polarity of the generator voltage to be reversed, and thus changes the direction of the drive.

If necessary, the drives can be accelerated or braked with maximum torque, a means of limitation in the control amplifier ensuring that an adjustable, permissible value is not exceeded.

The control amplifier depicted in Fig. 2, combined with the d.c. machine, forms that part of the drive which transmits the information received from the reference input unit faithfully and with the minimum time-lag to the planing machine.

Reference Input Unit

This unit (16 in Fig. 1) may be termed the "brain" of the drive. It receives commands or signals from different points, such as from the machine through contactless position indicators, or from monitoring devices on the machine, and by hand from push-buttons, switches or potentiometers. The unit, which employs a combination of digital and analogue principles, contains logic circuits designed for a definite operational sequence or programme. It is thus capable of making decisions, e.g. whether a command has to be executed at once or whether it can wait till later, what commands have priority, and so on. This also enables all interlocks to be incorporated in the system. The incoming digital and analogue information is converted, where necessary, in digital-to-analogue converters. These provide the necessary voltage function for reversal. The drive is then braked as a function of the speed, in such a way that the reversal point is always the same.

As shown in Fig. 3, the reference input unit is consistently constructed of plug-in elements on printed circuits. The chassis, which also plugs into a socket, has the same external dimensions as the control amplifier.

In order to eliminate the somewhat tiresome adjustment of the reversal point by means of dogs on the table, a process which can often only be carried out by frequent trial and error, a method was devised by which the adjustment of the travel can be easily, quickly and, above all, automatically correctly effected on the control desk. For this, the movement of the table is transmitted to an indicating system with a scale and pointers by means of a selsyn (9 and 10 in Fig. 1). The adjustment is then effected by running the table to the desired reversing point with the setting control, and then pushing the associated

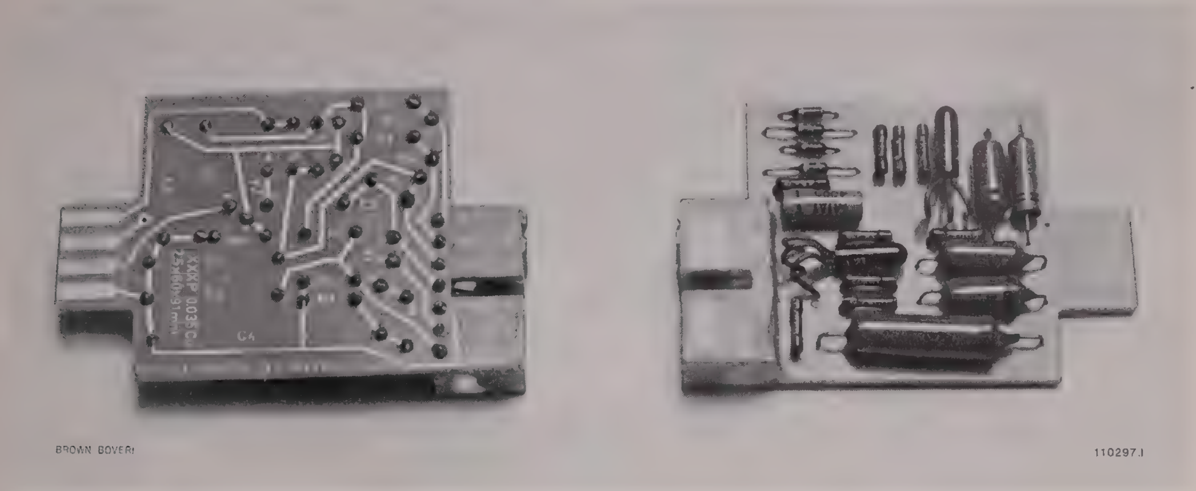


Fig. 4. – Oscillator position indicator

This contactless unit performs the task of the limit switches formerly used. It has no parts exposed to wear. By inserting a non-magnetic piece of metal between the two coils of the transistor oscillator, the oscillation is made to break off. An appropriate signal is produced by rectification and amplification.

pointer to its stop. When the pointer is released it is locked in this new position. The exact synchronism of the indicating system with the table of the machine is continuously checked by a special monitoring system. This is also aided by the position indicators which function on the oscillator principle and are described in detail below. An additional, independent safety system ensures that the table is stopped at the reversing point if the automatic electronic control should fail for any reason.

Oscillator Position Indicator

The oscillator position indicator, in its miniature plug-in design as used for this drive, is illustrated in Fig. 4. The indicator consists in principle of a transistorized oscillator with inductive negative feedback, the latter being reduced at the marking point by suitable damping to such an extent that the oscillation is abruptly broken off. In practice this is done by inserting a simple piece of non-magnetic metal 1–1·5 mm thick in the 4 mm wide air-gap between the main oscillator coil and the feedback coil. This piece of metal is part of the pointer mechanism marking the reversal point.

Fig. 5 shows the simplified circuit diagram. Each indicator consists of the oscillator part with the transistor T_1, rectification of the r.f. signal following amplitude limitation, and the emitter follower stage T_2 acting as output amplifier. The local generation of the oscillator frequency, and its rectification and amplification permit a relatively uncritical layout for the wiring, since no high frequencies leave the unit and the output circuit has a very low resistance. For introduction of the reference input for reversal,

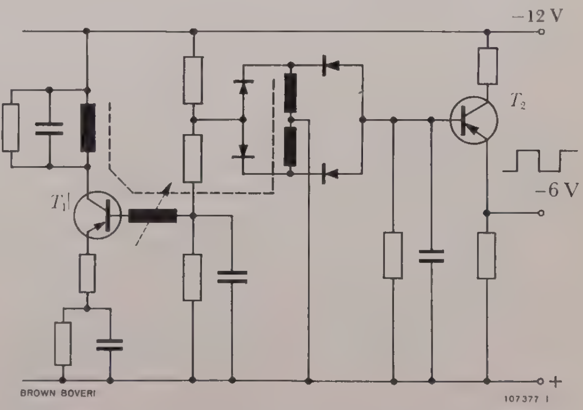


Fig. 5. – Schematic diagram of the oscillator position indicator

The circuit comprises the oscillator with transistor T_1, feedback, limitation and rectification of the r.f. oscillation, and the output amplifier T_2.

for the reversing point itself and for monitoring the synchronism between the table and the indicating system, a total of six such indicators are employed.

Drives designed on the principle described fulfil special requirements. Above all, they enable high working speeds and frequent reversal to be adopted. They keep their characteristic and precision in spite of external effects. They will be primarily used in those cases where the classical Ward-Leonard system no longer fulfils the stipulated conditions as well as required. They will prove particularly valuable for those machines which have already been automatized to a certain extent, e.g. by the provision of positioning devices. The necessary exchange of information between these two systems can then take place directly and with the necessary speed as regards transference and execution.

(KME) F. GLANTSCHNIG

AUTOMATIC CONTROL OF COOLING BEDS

621.771.2-52

Following a brief description of the manner in which a cooling bed functions, the article provides a mathematical analysis of the operating times which have to be controlled, and an account of the electronic timing relay which converts the previously calculated times into switching impulses. The article concludes with a reference to operational results.

THE MATERIAL emerging from a merchant rolling mill has to be cooled from the rolling temperature of 800–900 °C down to about 50 °C on a cooling bed before it can be cut into commercial lengths. The complete cooling bed consists of the bed proper, with approach roller tables, the rotating shears, the separator or deflector, the braking device, the swinging rake, shuffle bars and the outgoing roller table.

The rolled rod emerges from the last stand of the rolling train and is transported on the frequency-controlled roller table to the cooling bed. The rollers of the approach table must run at a speed 3–10 % in excess of that at which the rod emerges. This is attained by a frequency converter which obtains its desired frequency from the tacho-generator of the final stand. The 3–10 % increase in the speed of the roller motors is effected by varying the desired value set on the control pulpit by means of a potentiometer, thus preventing loops from forming. The percentage increase required depends on the gauge and shape of the rolled product.

The rolled rod is transported from the approach table to the cooling-bed shears where it is cut to the length of the bed. As soon as it has been cut, the end is brought to a standstill by the rising braking device, while the separator or diverter deflects the rod into the auxiliary channel. As soon as the first section has come to rest, it is thrown on to the eccentric rake system of the cooling bed by the braking ejector. When it has completed this action the braking device returns to its bottom position, ready to move up again and stop the subsequent length of rod. The length in the rake is lifted from the first into the second notch of the rake. This process is repeated regularly until the whole of the rolled rod has been cut to the length of the cooling bed and laid on the rake. With the arrival of each new length, those lengths on the rake are transported one stage further until they reach the shuffle-bar which finally dumps them on the delivery roller table.

Modern, continuous rolling trains are only economical when they operate at high exit speeds. But such high speeds demand very long cooling beds. In order to utilize the full length of the cooling bed it is essential for the tolerances in the length and position of the rods to be kept as small as possible, for which the impulses controlling the shears, diverter, braking device and rake have to be imparted with great accuracy. The shuffle-bar and delivery table are controlled by hand and do not form part of the automatic system.

Control System as Previously Used

Up to a few years ago the only method used for the control of such cooling beds employed contact control systems. Like cam control systems, these consist of a number of discs, each with a notch and a contact firmly assigned to it. This contact closes when its roller enters the notch in the disc, driven by a three-phase or d.c. motor. In the former case the motor is fed from the previously mentioned frequency converter of the approach roller table, whereas for the d.c. motor the desired value is provided by the tacho-generator of the final rolling stand. The drive is connected to the set of discs through a magnetic coupling. On arrival of the tip of the rod at the cooling bed, the magnetic coupling is switched on and the discs start to rotate. The impulses for the various other drives are then given when the particular disc comes into the appropriate position and closes its contacts. The disadvantage of this system is the difficulty experienced in setting; every change in the rolling programme necessitates a change in the impulse sequence. This means that almost every disc has to be readjusted. The greatest difficulty is experienced when an installation of this kind is being commissioned, because the settings cannot be calculated beforehand and therefore have to be worked out by trial and error. For all rolling programmes the settings have to be determined empirically and then set down in writing, which in turn means that the speed of leaving the final stand has to be kept constant for a certain shape, because the settings are primarily governed by the speed of the last stand. A further drawback is that changes of speed resulting from the necessary loop control in the final stand cannot be determined rapidly enough, owing to the inertia of the motor driving the contact system; therefore the length and position of the rods varies.

The stipulation of accuracy in the length and position of the rod by the rolling mill management arises out of the requirements of the cold shears which cut the finished rod into normal commercial lengths following the delivery roller table. Here a minimum of adjustment and as little wastage as possible are desired; these conditions can only be fulfilled when

(a) the rods on the cooling bed are as nearly equal in length as possible and this length is a multiple of the commercial length plus a little extra;

(b) the tips of the rods on the cooling bed are as nearly level as possible, thus reducing the amount of adjustment at the cold shears.

This work cannot be performed completely satisfactorily with the contact system; Brown Boveri have therefore developed an electronic system with which the impulses can be imparted to the drive controls with great precision.

Control by the Brown Boveri Electronic Timing Relay

Fig. 1 shows the principle of a single-strand cooling bed with the new control system. The impulses which switch on the drives of the shears and the cooling bed at the incoming end are imparted with great accuracy by three electronic timing relays. The sequence of these impulses is governed by the rolling speed v, the length to be cut l and the starting characteristics of the drives. If the rolling speed v were constant, the impulses would be given at fixed intervals for a certain length of rod. But in practice allowance has automatically to be made for variation in the rolling speed, and for free selection of the length within certain limits, regardless of the speed. A measure of the rolling speed is provided by the speed of the motor driving the final stand, measured by a tacho-generator and conveyed to the timing relay as a d.c. voltage input.

The actual control process begins at the moment the tip of the rod emerging from the final stand causes the photo-electric cell P_{I} to pick up. This transmits a command impulse to the timing relay Z_{I},

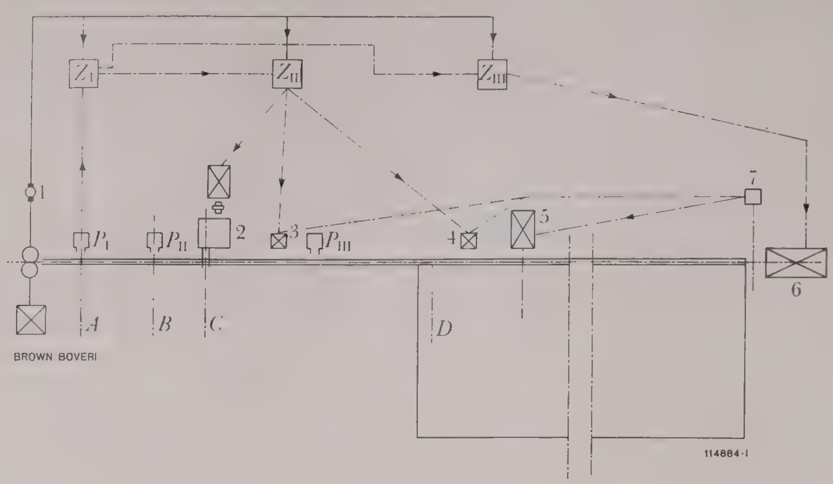


Fig. 1. – Electrical functions of a single-strand cooling bed

Z_I–Z_{III} = Electronic timing relays
P_I–P_{III} = Photo-electric cells
1 = Tacho-generator
2 = Cooling-bed shears
3 = Diverter
4 = Auxiliary channel
5 = Eccentric rake
6 = Ejector
7 = Cam control

which runs until a length l has passed the photocell, the time for which is given by $t = l/v$. On expiry of this time the timing relays Z_{II} and Z_{III} receive switching impulses from Z_I. The latter starts to run again and registers another length l. In the meantime the first length of rod has run into the main channel and as soon as the tail of this rod has approached to within a distance $v.t$ of the shears (rolling speed times the starting time of the shears), relay Z_{II} emits a switching impulse for the shears, which cut when the run-up time expires. To prevent the second rod from running into the same channel, the diverter 3 and the separator forming the auxiliary channel 4 are set in motion at the same time as the shears. The rod 1, which is running forwards on the rollers of the main channel, must therefore be braked in such a way that its tail-end comes to rest about 2 m beyond the beginning of the cooling bed (point D in Fig. 1). For this relay Z_{III} gives the ejector 6 an order to move downwards. When it has reached the position 1 (Fig. 3) the rod slides down the inclined rollers of the main channel on to the braking device, where it is brought to rest and thrown over the guide bar on to the swinging rake of the cooling bed. The storage time of relay Z_{III} is given by the time taken by the tail-end to travel the distance AD (Fig. 1) less the braking time of the rod and about 1·5 s, the time taken by the ejector to travel from 0 to 1.

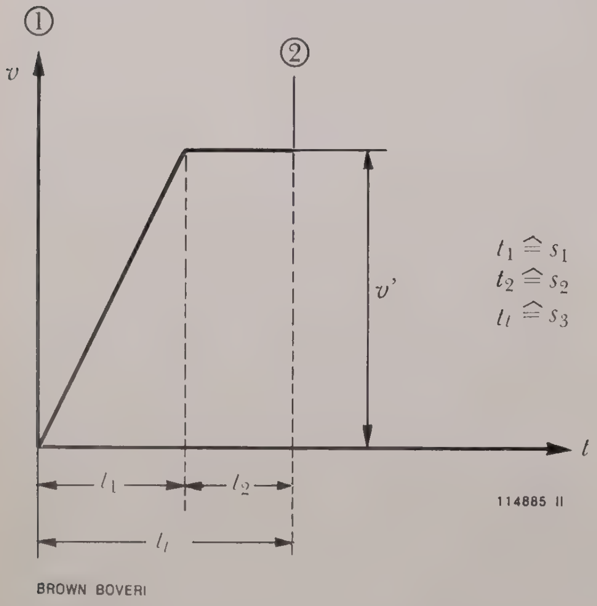


Fig. 2. – Starting curve of a flying shears

Abscissae: time Ordinates: speed

1 = Application of impulse
2 = Moment of cutting
t_1 = Time for shears to run up
t_2 = Time between end of run-up and cutting
t_t = Total time from impulse to cutting
s_1, s_2, s_3 = Distance travelled by stock in times t_1, t_2, t_t
v, v' = Speeds (see p. 139)

When the braking device with the first rod has risen, the main channel is free to accept the second rod. The bar forming the auxiliary channel and the diverter are then returned to their original positions by the cam control 7 (Fig. 1) of the ejector 6, when the first rod has come to rest. The second rod then slides into the main channel and undergoes the same treatment as the first; the third and following rods likewise.

If a tail-end piece, shorter than the desired length, is followed immediately by the head of a new piece, the latter enters the same channel. Therefore a means must be provided which allows the desired length to be cut every time, even when this is made up of a tail-end and a head, with an intervening space.

Tail-ends under about 2·5 m length, for instance, must not be cut because they cannot be reliably transported. Consequently the distance between the photocell P_{I} and the cutting point at the moment the shears are switched on is at least 2·5 m. If the cell P_{I} is no longer illuminated, the cutting command is blocked by relay Z_{II}. This reliably prevents pieces less than 2·5 m long from being cut. Also pieces which have to be cut from the rod following the tail-end must not be shorter than a definite minimum length. This is supervised by photocells P_{II} and P_{III} (Fig. 1).

The Electronic Timing Relay for Automatic Control of Cooling Beds

Mathematical analysis of storage times depending on the rolling speed

The next chapter will be devoted to a closer study of the storage times depending on the rolling speed v.

The storage time of relay Z_{I} is

$$t_{\mathrm{I}} = \frac{l}{v} \qquad (1)$$

where l = length of material cut

v = rolling speed.

On expiry of the period t_{I} impulses are applied simultaneously to the timing relays Z_{II} and Z_{III}. For the analysis of the storage times of these relays, it must be borne in mind that the peripheral speed v' of the flying shears and that of the transport rollers of the cooling bed are 3–10% higher than the actual rolling speed v. The storage time of relay Z_{II} is given by

$$t_{\mathrm{II}} = \frac{\overline{AC}}{v} - t_t \qquad (2)$$

in which t_t is the starting time of the shears drive, during which the end of the rod travels the distance $\overline{BC}$ (Fig. 1). At point B the impulse must be given to switch on the shears. For shears which are accelerated to the speed v' at constant torque, there is a time-lag between the moment the shears are switched on and the instant at which cutting takes place; this is given by $t_t = t_1 + t_2$ (Fig. 2). The distance the cutter blade has to travel from a fixed starting point in this period is s_3; the time t_1 corresponds to the distance s_1, the time t_2 to the distance s_2. With

$$t_2 = \frac{s_3 - s_1}{v'} \quad \text{and} \quad s_1 = \frac{v' \cdot t_1}{2}$$

we obtain

$$t_t = t_1 + \frac{s_3 - \dfrac{v' \cdot t_1}{2}}{v'} \qquad (3)$$

$$t_t = \frac{t_1}{2} + \frac{s_3}{v'}$$

The relationship between the time T_a taken by the shears to reach $v'_{max} = 1{\cdot}1\ v_{max}$, and the time t_1 is as follows

$$\frac{t_1}{T_a} = \frac{v'}{v'_{max}} = \frac{v}{v_{max}} \qquad (4)$$

Thus $$t_t = \frac{s_3}{1{\cdot}1\ v} + \frac{T_a v}{2\ v_{max}}$$

If we now substitute this value in the equation (2) we obtain the following storage time for relay Z_{II}

$$t_{\mathrm{II}} = \frac{\overline{AC}}{v} - \frac{s_3}{1{\cdot}1\ v} - \frac{T_a v}{2\ v_{max}} \qquad (5)$$

$$t_{\mathrm{II}} = \frac{\overline{AC} - \dfrac{s_3}{1{\cdot}1}}{v} - \frac{T_a v}{2\ v_{max}}$$

Example: $\overline{AC} = 9$ m

$s_3 = 4{\cdot}8$ m

$v_{max} = 10$ m/s

$T_a = 0{\cdot}52\ s$

Substituted in the above formula (5) these values give

$$t_{\mathrm{II}} = \frac{4{\cdot}57}{v} - 0{\cdot}026 v$$

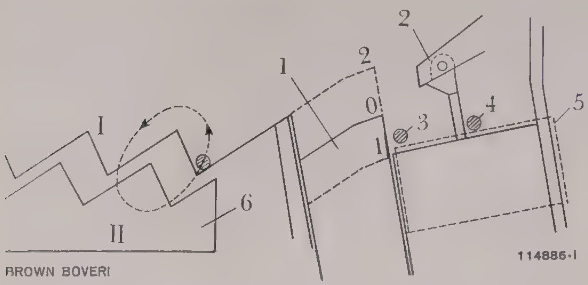


Fig. 3. – Illustrating the mechanical functions of a single-strand cooling bed

1 = Braking device
2 = Separator forming auxiliary channel
3 = Rod 1
4 = Rod 2
5 = Roller table
6 = Eccentric rake
I = Fixed part
II = Moving part

The rods in the fixed part I of the rake are progressively carried one notch forward by the eccentric movement of the moving part II.

Now at the same instant as an impulse was applied to Z_{II} by Z_I, another was also applied to Z_{III}. At this moment the end of the rod is at the point A. Therefore to reach the position of rest (after braking) the rod has to travel the distance $\overline{AD}$, which corresponds to a storage time of

$$t_{III} = \frac{\overline{AC}}{v} + t'_{III}$$

To calculate the time t'_{III}, it must be remembered that the ejector (Fig. 3) requires a time of $t_A = 1{\cdot}5$ s to raise the rod and initiate braking. Hence the rod is not stopped at once but covers a braking path of

$$s_B = \frac{(1{\cdot}1\ v)^2}{2\ \mu g}$$

before it comes to rest. In this expression

$1{\cdot}1\ v$ = speed when braking starts
μ = coefficient of friction of the rod on the braking device
$g = 9{\cdot}81$ m/s²

Hence

$$t'_{III} = \frac{\overline{CD} - s_B}{1{\cdot}1\ v} - t_A$$

$$= \frac{\overline{CD}}{1{\cdot}1 v} - t_A - \frac{1{\cdot}1 v}{2 \mu g}$$

The storage time of the timing relay Z_{III} is

$$t_{III} = \frac{\overline{AC}}{v} + \frac{\overline{CD}}{1{\cdot}1 v} - t_A - \frac{1{\cdot}1 v}{2 \mu g}$$

$$t_{III} = \left(\overline{AC} + \frac{\overline{CD}}{1{\cdot}1}\right) \cdot \frac{1}{v} - t_A - \frac{1{\cdot}1}{2 \mu g} \cdot v$$

For example, when

$$\overline{AC} = 9 \text{ m}$$
$$\overline{CD} = 30 \text{ m}$$
$$\mu = 0{\cdot}3$$
$$t_A \doteq 1{\cdot}5 \text{ s}$$

$$t_{III} = \left(9 + \frac{30}{1{\cdot}1}\right) \cdot \frac{1}{v} - 1{\cdot}5 - \frac{1{\cdot}1}{2.0{\cdot}3.9{\cdot}81} \cdot v$$

$$= \frac{36{\cdot}3}{v} - 1{\cdot}5 - 0{\cdot}187 v \text{ [s]}$$

From the above derivation it is evident that the foregoing storage time functions are of the form

$$t = \frac{k_1}{v} - k_2 - k_3 v$$

in which, for relay Z_I the constants k_2 and k_3 are zero, while for Z_{II} the constant k_2 is zero.

The electronic timing relay is equipped with three knobs calibrated in m, s²/m and s, respectively, by means of which the constants k_1, k_2 and k_3 can be infinitely adjusted between zero and maximum. The ease with which the relays are operated and placed in service is a direct outcome of being able to set the constants k_1, k_2 and k_3 on the unit itself. After commissioning, the work of adjustment before or during rolling is confined to setting the length to be cut and possibly correcting the friction conditions and thus the position of the rod.

When the timing relay was being developed, special stress was laid on the ability to exactly reproduce a time once set, i.e. with a minimum tolerance. The need for this is obvious when it is considered that a difference of only 1 ms produces an error in length of 10 mm. Some idea of the accuracy achieved may be gained from Fig. 4, in which a number of points are plotted for different settings of the time-lag of the relay.

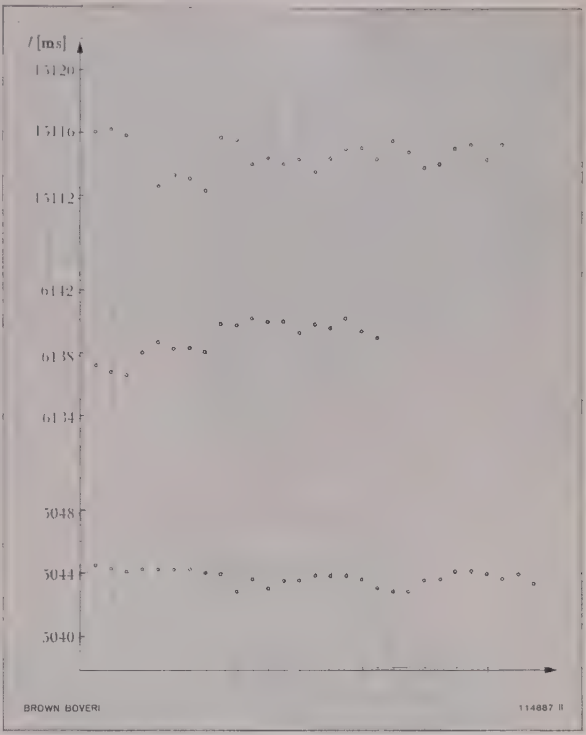


Fig. 4. – Scatter of the electronic timing relay at three different time settings

The diagram, in which a series of points measured with different settings of the operating time t are plotted, clearly demonstrates the accuracy of the relay.

The internal circuit of the electronic timing relay is based on the time function

$$k'_1 - k'_2 v - k'_3 v^2$$

(see the circuit diagram in Fig. 5), in which k'_1 represents a constant voltage, and $k'_3 v^2$ is a voltage obtained from a function generator consisting of semiconductor diodes and resistors. The quantities k'_1, k'_2 and k'_3 can be adjusted infinitely between zero and maximum on linearly calibrated precision potentiometers. The currents corresponding to the three partial voltages are added by the three resistances R_1, R_2 and R_3 and at the input to the ampli-

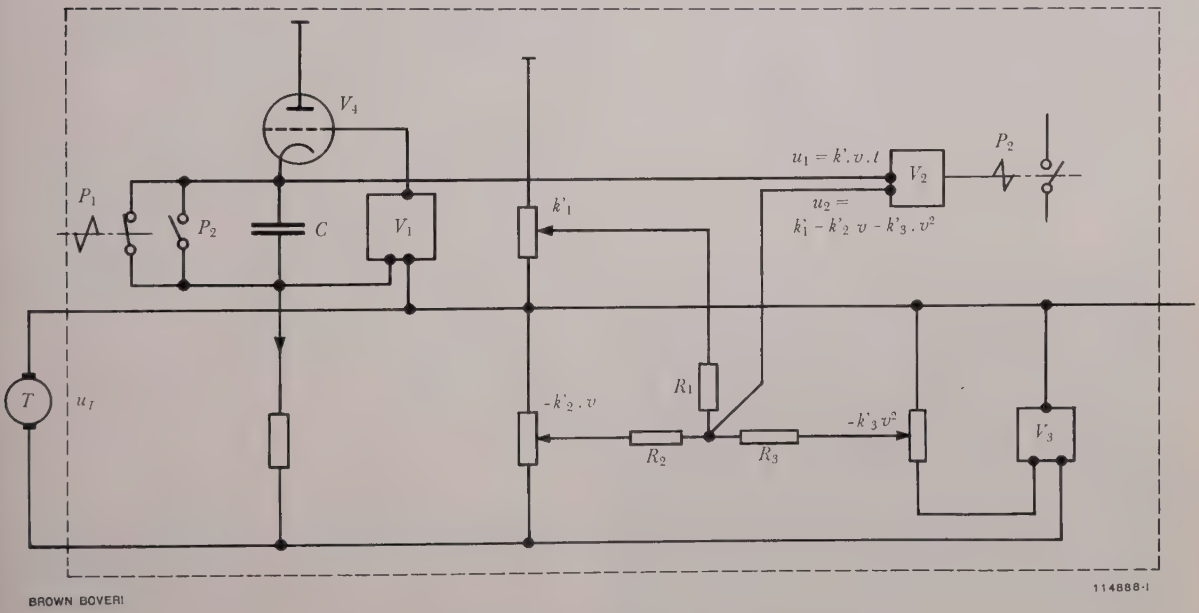


Fig. 5. – Circuit diagram of the electronic timing relay

k'_1, k'_2, k'_3 = Infinitely variable constants
V_1 = Current controller
V_2 = Electronic amplifier for comparing voltages
V_3 = Function generator
V_4 = Amplifier tube
R_1, R_2, R_3 = Resistors for adding voltage

C = Capacitor
P_1 = Relay for making
P_2 = Relay for emission of impulse and resetting
T = Tacho-generator fitted to the motor driving the final rolling stand

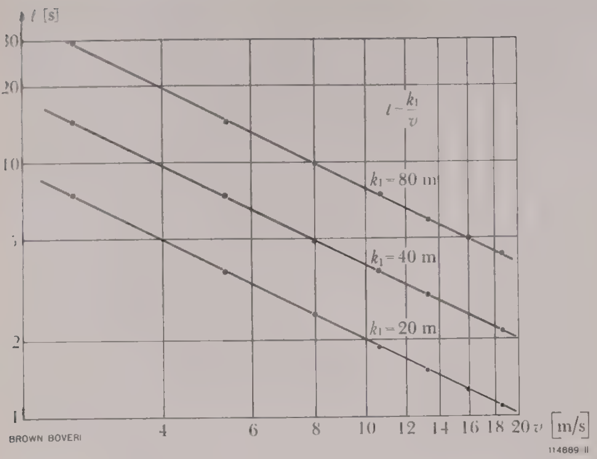


Fig. 6. – Times for cutting at different rolling speeds with the cut length as parameter

v = Rolling speed in m/s
t = Time in s

fier V_2 provide a voltage (u_2) which can be compared with a voltage u_1 dependent on time. The latter is produced by charging a capacitor C, the charging current of which is kept proportional to v by a current-regulating network V_1

$$u_1 = k' v t$$

If the voltage added by the resistors R_1, R_2, R_3

$$u_2 = k'_1 - k'_2 v - k'_3 v^2$$

equals the capacitor voltage, we may write

$$k' v t = k'_1 - k'_2 v - k'_3 v^2$$

or

$$t = \frac{k_1}{v} - k_2 - k_3 v$$

which is the desired storage time function.

The equality of the voltages u_1 and u_2 is determined by the amplifier V_2, the output circuit of which contains a relay for the outward transmission of the impulses. A second contact of the same relay discharges the capacitor in a maximum of 20 ms, following which charging can begin again. The conventional auxiliary circuits are also provided, enabling the timing relay to be switched by an impulse or by a sustained command. In the latter case the unit acts as a time-base. It is switched on by a relay contact which allows the capacitor to be charged.

Adjustment of the constants k_1, k_2, k_3 is performed by precision potentiometers graduated in 0·1% and mounted in the unit or externally on a control desk, terminals being provided for their connection in the latter case. To check the relay, the starting command can be given by a push-button mounted on the unit. While it is running, a pilot lamp lights, providing an easy means of checking the indicated time. The input energy quantity—tacho-generator voltage representing the rolling speed—is generated internally by throwing a switch, and can be infinitely varied between 0 and 150 V by a potentiometer.

Technical Data

Time range		0·1–35 s
Accuracy of setting		
constants k_1 and k_2		±2 %
constant k_3		±4 %
Maximum drift in eight hours		0·1% of the set time
Functional accuracy of all components		better than 2 %
Scatter in time due to ±10 % fluctuation in mains voltage		<0·1%
Input		20–150 V d.c. with a load of 7·5 kΩ
Service voltage		220 V, 50 c/s
Consumption		110 W
Contact rating	a.c.	220 V 6 A
	d.c.	60 V 6 A 100 V 2 A 200 V 0·5 A

For a rolling speed of v = 3–20 m/s, corresponding to an input of 22·5–150 V, a time function of

$$t = \frac{0-100\ [\mathrm{m}]}{v} - 0\text{–}10\ [\mathrm{s}] - 0\text{–}0{\cdot}5 \left[\frac{\mathrm{s}^2}{\mathrm{m}}\right] \cdot v$$

is obtained. A range switch allows the adjustment to be made in three ranges, on the second and third of which the maximum values stated above are reduced in the ratio 1:2 and 1:4, respectively.

Fig. 6 shows various series of time measurements to illustrate the functional accuracy for the k_1/v part, k_2 and k_3 being made zero to make the picture clearer. Their parts, however, yield very similar results. Owing to the use of the logarithmic scale, their linearity is a direct measure of the functional accuracy.

Constructional Design of the Electronic Timing Relay

The relay (Fig. 7) is constructed as a drawout unit with plug contacts at the rear, which facilitates inspection and replacement. It can be mounted in any position in control desks or cabinets. To ensure long life with a high standard of reliability and accuracy, only well-tried and carefully dimensioned industrial, electrical and electronic components are used. Special circuit arrangements prevent the operation of the unit from being affected by disturbances, such as ageing, thermal migration and fluctuation of the mains supply.

Experience with Electronically Controlled Cooling Beds

In 1958 Brown Boveri equipped two cooling beds for merchant mills with the electronic timing relays described and took them into service successfully. One of these was the cooling bed supplied by Demag, Duisburg, to Terni Società per l'Industria e l'Elettricità, for their steelworks at Terni near Rome. The rolling mill was equipped with electrical equipment made by Tecnomasio Italiano Brown Boveri, Milan, while the main drive controls and, in particular, the automatic system for the cooling bed was ordered from Brown Boveri, Baden. The second installation is a two-strand cooling bed 60 m long, built by Siemag, Dahlbruch, Germany, for the Monteforno Steelworks at Bodio, Switzerland, with Brown Boveri electrical equipment. This installation was taken into service in only a few days, tolerances of ±10 cm being attained immediately after commissioning with rods 55 m long and a rolling speed of 6 m/s. Later measurements on rods

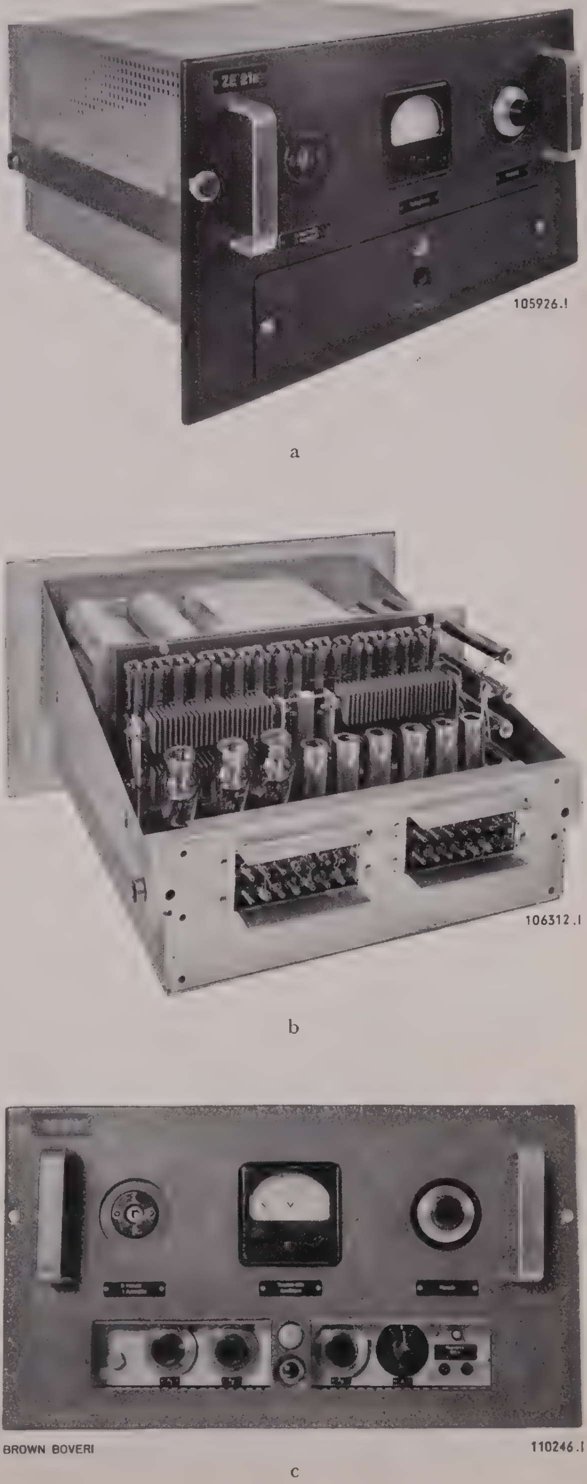


Fig. 7. – Electronic timing relay for controlling cooling beds

a: Front view, enclosed

b: Rear view, with protective cover removed

c: Front view, with covers removed from control and test elements

45 m long showed the maximum tolerance to be ±5 cm. Both customers have written confirming their satisfaction with the Brown Boveri control system. Above all they appreciate the speed with which operation can be restarted after a change in the rolling programme, and the ability to adjust the length cut, the position of the rod and the coefficient of friction while rolling is in progress. The easy means of altering the length of the rod also enables the amount of waste at the cold shears to be minimized by choosing suitable cutting lengths.

At the beginning of 1960 a further cooling bed with this system of control will be taken into service in the Jamshedpur steelworks of the Tata Iron and Steel Co. in India. The cooling bed, like the merchant mill to which it belongs, was supplied by Schloemann of Dusseldorf and is equipped with Brown Boveri electrical equipment. For the extensive programme specified by the customer, which visualizes rods of several different cross-sections, the cooling-bed control must fulfil the following conditions:

1. Normal operation as described;
2. Normal operation but with two lengths parallel in one notch of the rake;
3. Operation of the cooling bed without shears, in which case the length rolled from one billet does not exceed the length of the bed.
4. Operation of the cooling bed without shears, the length rolled from one billet not exceeding 45 % of the length of the cooling bed. In this case the first length is braked in the second half (furthest from the rolling stand) of the cooling bed, and the second length is braked in the near half; the two lengths are then head-to-tail in one notch of the rake.

These different procedures are needed to enable the rods of all the cross-sections which are produced to be properly cooled. For changing from one procedure to another a selector switch is provided on the control pulpit.

The electronic timing relay described was developed specifically for controlling cooling beds, in which capacity it has proved ideal. But its properties are such that it can be employed in any situation where an action has to be switched on and off at intervals depending on a certain input value. By carefully selecting and dimensioning the components, a unit has been produced which is very reliable, easy to operate and very accurate. It fulfils the severe requirements of heavy industry and offers some interesting possibilities for the solution of problems connected with the automation of a wide variety of industrial processes.

(KME)

W. Pohl
H. R. Kunz

CORELESS MAINS-FREQUENCY CRUCIBLE INDUCTION FURNACES

621.365.5

This article gives an account of the development and standardization of the Brown Boveri mains-frequency crucible induction furnace used for melting iron and light alloys. The description of a typical installation follows some remarks on the metallurgy, the most important applications and the economical employment of these furnaces.

WHEREAS medium-frequency induction furnaces have been built for about 40 years, the development of mains-frequency crucible induction furnaces began in 1945 as a special design (see colour plate inside front cover). At that time the first trials with a furnace for holding and superheating molten iron were carried out by Brown Boveri in a foundry in Northern Italy, with very good results.

The first furnaces had only a low specific electric input and were used for superheating a liquid charge with a weak stirring effect in the melt. In recent years the specific input of this new type of furnace has been greatly increased. Despite the increased stirring effect in the melt, the durability of the crucibles proved good, so that this kind of furnace is now an ideal and very economical furnace for melting grey iron and light alloys. This type of furnace avoids certain marked drawbacks of the submerged channel type and, in contrast to medium-frequency furnaces, dispenses with the rotating frequency converter.

The principle of transferring the energy to the metal charge by means of an alternating magnetic field is exactly the same as in the medium-frequency furnace. The much lower working frequency (50 or 60 c/s) compared with the latter, for physical reasons, imposes a lower limit for the capacity and, when melting from cold, on the dimensions of the charged material in mains-frequency furnaces. In the other direction the maximum input is restricted by the proportional increase in stirring effect as the power is increased.

For steel and grey iron the smallest economical furnace has a crucible with a capacity of about 800 kg, for light alloys about 300 kg and for heavy non-ferrous alloys about 1000 kg. When melting from cold, i.e. with solid charge, the latter should consist of solid lumps, with grey iron at least 25 cm in size. In practice "starting blocks" are used, composed of returns, scrap and ladle skull, formed to the crucible dimension in a suitable sand mould or in a simple ingot mould. In quantity it should amount to at least 15% of the total capacity of the crucible. When the blocks are melted small pieces of metal, e.g. swarf, bulky light scrap, etc., may subsequently be added. The above, undesired charge for cupola furnaces, can be melted very economically in an induction furnace with a minimum of oxidization loss. When suitably charged, it is possible to melt light alloys from cold with pigs weighing only 4 kg [1].[1]

The mains-frequency induction furnace, having a crucible capacity of 0·8–12 t or more, is an ideal furnace for remelting or alloying grey iron, or special cast iron, such as nodular or malleable cast iron. It is an ideal heatable mixer for duplex operation with a cold-blast cupola furnace or arc furnace for accurate correction of the analysis or temperature, as well as being useful as a means of storing molten metal in

---

[1] The figures in square brackets refer to the bibliography at the end of the article.

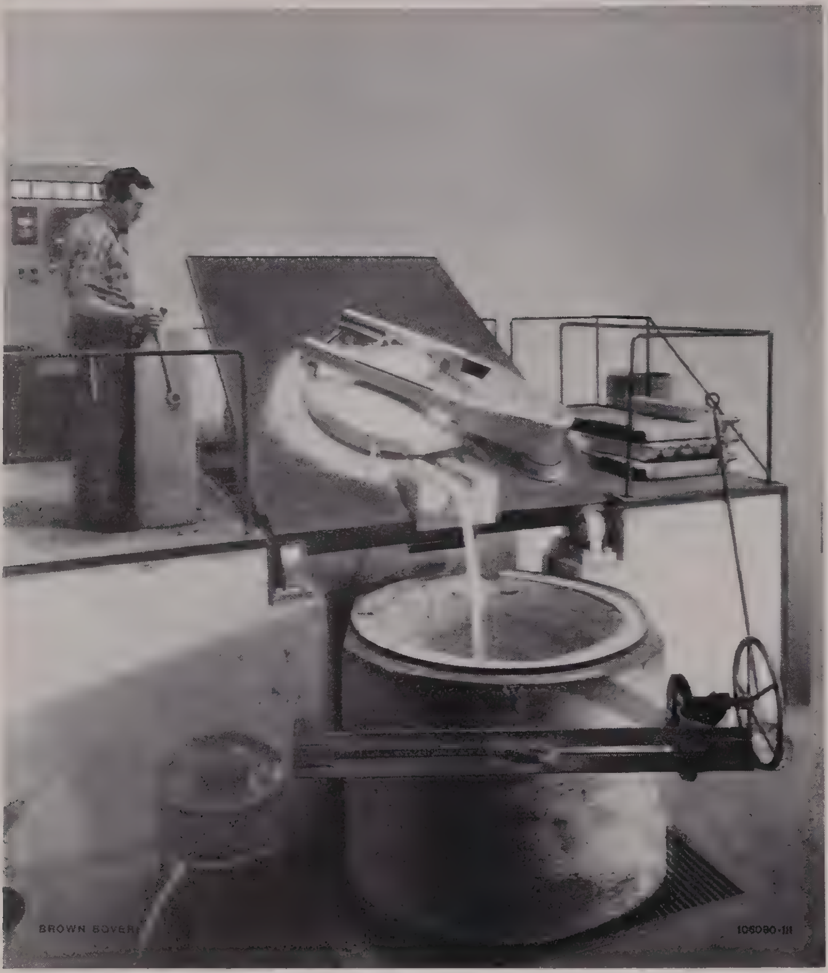


Fig. 1. – Pouring a 1·2-t light-metal furnace

Rated input	260 kW
Maximum input	320 kW

Hourly melting rate at 700 °C: 475 kg continuous output, not allowing time for charging, alloying, pouring and holding.

Power consumption appr. 550 kWh/t

foundries where the demand is irregular. It is an excellent means of tiding over individual charges of discontinuous arc melting furnaces feeding continuous casting furnaces with molten iron.

Economics of Mains-Frequency Furnaces

For melting grey iron the mains-frequency induction furnace is the most economical electric furnace. When melting down swarf and bulky lightweight scrap for the synthesis of grey cast iron, the loss of metal is extremely small. Compared with arc furnaces the thermal stress on the refractory lining is very much less, thus reducing wear, and there is no electrode consumption. Besides being inexpensive to maintain, it is also economical with regard to power consumption. This is very pronounced in discontinuous operation, since the low heat storage of the crucible when starting from cold only increases the power consumption by 10–12% above that for melting with the furnace hot from operation. The power company is also favourably disposed towards the induction furnace, on account of its high power factor and the absence of surges on the supply system.

Metallurgical Properties of the Mains-Frequency Induction Furnace

From the metallurgical aspect the mains-frequency induction furnace is primarily suited to remelting and alloying. In contrast to the arc furnace, it is not possible to perform any effective slag treatment such as refining, because the slag (a poor conductor of electricity) is colder than the molten metal on which it floats. The small amount of oxidization of the metal and alloying elements ensures that the

TABLE I

Mean values of gas contained in cast iron melted in different types of furnaces [2]

	Gas content in cm³/100 g			
	Total	O_2	H_2	N_2
Cupola	10·6	1·7	2·7	6·2
Arc	9·7	1·1	2·0	6·6
Mains-frequency induction	7·1	1·1	2·3	3·7

desired alloy is obtained easily and accurately, and enables the melt to be held for long periods without changing the analysis. The powerful stirring effect produces a well-mixed homogeneous melt and allows carburizing substances to be absorbed with a minimum of waste. Since the heat is generated by induction in the metal itself, there is no possibility of local overheating. Metallurgically this is very favourable: as may be seen in Table I the gas content of cast iron is very low, so that castings are much less porous [2].

Induction heating is an ideal method for superheating the melt rapidly and efficiently to the optimum pouring temperature, while maintaining constant analysis. The metallurgist particularly appreciates the ease with which the control of the temperature of the melt is adapted to requirements of the alloying or casting processes. The temperature control of the induction furnace, which is recognized as most favourable, can also be accurately reproduced. This ensures that castings poured from successive charges are all of a uniform quality. Should it be necessary to correct the analysis after performing tests on specimens taken at about 1200 °C, this can easily be carried out without loss of time while the melt is being superheated up to the pouring temperature.

The metallurgical facilities of the mains-frequency induction furnace for carburizing or diluting iron melts, the amount of oxidization during alloying and the reaction between the melt and the crucible at different temperatures were studied by the Battelle Institute, Frankfurt, on behalf of Brown Boveri, in a series of exhaustive investigations. Since 1955 reports on these have been repeatedly published in the periodical "Giesserei" [3].

Standardization of Mains-Frequency Induction Furnaces

The economic efficiency and metallurgical advantages of the mains-frequency induction furnace have led to a great increase in the popularity of these furnaces, especially in iron-foundries. The sizes of furnaces on which Brown Boveri standardized are shown in the Tables II and III. The melting and superheating rates listed therein apply to crucibles in their new state, before the movement of the melt has had any effect, assuming rated input and an initial liquid charge of about two thirds of the total capacity. If the charge is below the top of the induction coil, the electrical input and the output of metal decrease. The rated input can be forced into the furnace, even when it is only partly filled, thereby reducing the time for melting down from cold. To do this it is convenient for the mains transformer to have two tappings, increasing the mains voltage by 5 and 10%. Brown Boveri furnaces may carry a sustained overvoltage of 10%, and an overcurrent of up to 15%. From the power aspect the whole installation is designed to withstand an overload of up to 25%. When the crucible is slightly worn, the furnace may be run at 25% excess power on the highest voltage tapping. Foundries like to take advantage of this reserve of power because the energy consumption per ton becomes smaller, the shorter the melting period (see Table II).

Design of the Mains-Frequency Induction Furnace and Layout of the Installation

Design of the Furnace

The Brown Boveri mains-frequency crucible furnace has amply dimensioned iron yokes to improve the power factor and to prevent the compact frame from being overheated. Inside these yokes is the water-cooled induction coil of hollow copper section.

The furnace, supported by two bearings in line with the spout, can be tilted hydraulically at variable speed by means of a manual control valve. The tilting cylinders are mounted one on each side of the furnace, below the platform. The furnace is connected to the mains by flexible, water-cooled

TABLE II

Standardized Brown Boveri mains-frequency crucible induction furnaces for grey iron

Type ISNG	Maximum crucible capacity	Rated input		Melting and superheating rate at 1450 °C [1]	Power consumption [1]	Superheating rate/h for 100 °C rise in temperature between 1250 and 1450 °C	Power consumption per t and 100 °C superheating
	kg	appr. kW	kVA	appr. kg/h	appr. kWh/t	appr. kg/h	appr. kWh/t
0·8/120	860	120	150	150	825	2 200	57
0·8/320	860	320	400	540	600	8 000	41·5
1·5/320	1 500	320	400	540	595	8 000	40
1·5/450	1 500	450	560	800	565	11 500	39
3·5/450	3 700	450	560	810	555	11 700	38·5
3·5/600	3 500	600	750	1100	540	16 000	37·5
3·5/720	3 500	720	900	1350	530	19 400	37
3·5/800	3 400	800	1000	1550	520	22 000	36·5
4·5/450	4 800	450	560	800	560	11 600	39
4·5/600	4 560	600	750	1130	540	16 400	36·5
4·5/800	4 500	800	1000	1550	520	22 400	36
4·5/1000	4 500	1000	1250	2000	500	28 800	35
6/450	6 400	450	560	790	570	11 400	39
6/600	6 400	600	750	1140	540	16 000	36·5
6/800	6 100	800	1000	1550	520	22 000	36
6/1100	6 000	1100	1400	2220	500	32 000	34·5
8/450	8 450	450	560	780	570	11 200	40
8/800	8 450	800	1000	1570	520	22 600	36
8/1400	8 100	1400	1800	2830	490	40 800	34
12/600	12 600	600	750	1100	550	16 000	38
12/1000	12 000	1000	1000	1940	520	28 000	35

[1] Melting and superheating rate up to 1450 °C in continuous operation with hot furnace; with liquid charge (1450 °C) of two-thirds rated capacity, for cold, bulky charge at rated power, not allowing for charging, deslagging, alloying, pouring, holding, etc. With one-third initial liquid charge the melting rate is reduced by 5–10%.

leads allowing current to be supplied even when the furnace is tilted. By slightly tilting the furnace bulky material in the charge can be prevented from bridging across the crucible.

The thermal insulation of the crucible consists of asbestos, insulating bricks and heat-resistant mortar. A tight-fitting, insulated cover prevents heat from being lost upwards. To facilitate charging from the rear platform, the cover can be raised vertically and swivelled to one side by means of a second hydraulic control valve; only on the smallest furnace is this action performed by hand. On the larger sizes, an

TABLE III

Standardized Brown Boveri mains-frequency crucible induction furnaces for light alloys (Fig. 1)

Type ISNA	Crucible capacity	Rated input		Melting rate up to 700 °C [1]	Power consumption[1]
	kg	kW	kVA	appr. kg/h	appr. kWh/t
0·3	300	110	125	185	585
0·6	600	160	180	280	570
1·2	1200	260	315	475	550
2·1	2100	480	560	900	540
3·0	3000	700	800	1250	540
4·5	4500	1000	1200	1800	540

[1] In continuous operation at up to 700 °C, with liquid initial charge of approx. one third the capacity of the furnace, not allowing for pouring, recharging, cleaning and holding.

additional sliding lid allows the furnace to be charged with small scrap or swarf, and such tasks as deslagging, alloying and removal of specimens can be performed with a minimum loss of heat. The smelter is also effectively protected against radiation and possible splashes of metal. The hydraulic system comprises a vertical screw pump immersed in an oil tank, a safely valve and the built-on motor.

On account of the heavy current it has to carry, and the heat continuously dissipated by the crucible, the furnace coil is water-cooled. Since interruption of the water supply for more than 10 minutes, when the furnace is at the operational temperature, can overheat the coil insulation and possibly damage it, the provision of an absolutely reliable cooling-water system, e.g. with an emergency tank, is essential. This is also advisable when the water supply depends on pumps which may stop if their power supply fails. Also important is efficient monitoring of the water supply; this is undertaken by a pressure relay on the water input side of the induction coil and a thermostat in each water outlet. If cooling proves insufficient, these immediately interrupt the power after giving a visible and audible warning. If plenty of pure, soft water is available for cooling, it is advisable to include a mixing tank in which the cooling water can be slightly preheated. This prevents moisture from condensing on the furnace. During melting, the rate of flow of cooling water

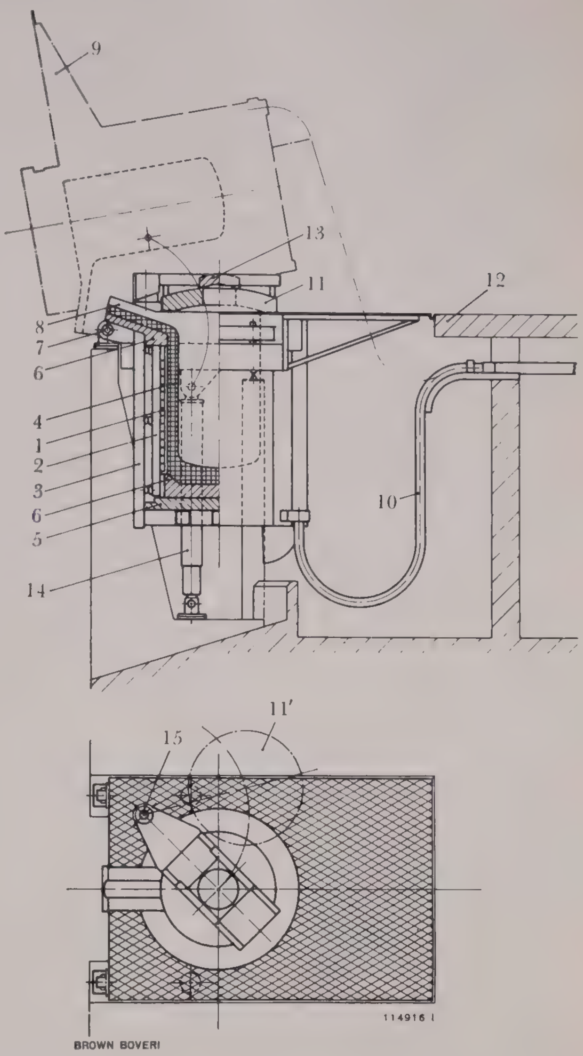


Fig. 2. – Arrangement of the coreless mains-frequency induction furnace

1 = Water-cooled induction coil
2 = Iron yokes
3 = Furnace frame
4 = Crucible (acid mass)
5 = Insulating bricks
6 = Heat-resistant cement
7 = Tilting bearings
8 = Spout
9 = Final tilted position
10 = Water-cooled power cable
11 = Swivelling cover
11′ = Final position of cover
12 = Platform
13 = Sliding lid
14 = Tilting cylinder
15 = Cover lifting cylinder

only needs to be sufficient to prevent the temperature on the outlet side of the coil from exceeding 65 °C. If the water is hard or aggressive, an additional closed-circuit cooling system containing soft water should be used to avoid incrustation and corrosion. In installations where water is scarce or expensive, air or evaporation coolers are worth considering.

Ramming Material for the Crucible

The thinner the crucible, the higher the efficiency and power factor of the induction furnace. This rather limits the choice of ramming materials which may be used. For mains-frequency induction furnaces melting steel and grey iron the most suitable material has, with few exceptions, proved to be acid quartzite material, comprising about 99% SiO_2 with a sintering additive of 0·5–2·4% boric acid, depending on the temperature likely to be used most. Apart from the care taken with ramming—assuming the proper grain distribution and uniform mixing of the sintering agent—the durability of the crucible depends largely on sintering being carried out properly, the state of the scrap-metal—very rusty scrap is unsuitable—the operating conditions and the temperature of the melt. When producing ordinary cast iron the wear on the crucible amounts to between 1 and 3·5 kg per ton of liquid iron, depending on the size of the furnace, the pouring temperature and the mode of operation. For special products such as malleable or nodular cast iron, with pouring temperatures above 1500 °C, the wear on the crucible is around the upper limit stated above.

The local wear of the lining due to the washing effect of the molten metal can be patched up at convenient intervals, before the crucible has to be relined. When used for single-shift work with overnight holding, a 4·5-t high-output furnace melted over 3000 t of liquid iron with the same crucible. During its "useful life" the crucible was patched four times.

In spite of the numerous experiments which have been performed with basic crucible masses, it has so far only been possible to achieve quite small throughputs. In the high-power induction furnace the stirring effect is too severe for the basic lining. Furnaces for light alloys are lined with a ramming mass based on aluminium silicate [1].

Electric Switchgear

Fig. 3 and 4 show the circuit diagrams for single and three-phase operation. The supply to the furnace is switched on progressively in two stages; the first stage by means of the starting contactor with a resistor in series; the change to full load is later effected by a second contactor. The control board contains all the instruments, kWh-meters, time-lag relays, programme switches and controls for operation of the furnace. A bank of capacitors (Fig. 8) in parallel with the induction coil improves the power factor selectively to about 0·85 with single-phase supply, or to about unity with three-phase supply. The air-cooled capacitor bank comprises the basic step, amounting to 30-40% of the total capacitance, and 15 further steps. These are successively cut in automatically during the melting process as the degree of filling increases. The amply dimensioned capacitor contactors are controlled at roughly half-load by a programming mechanism, actuated by the automatic controller. The capacitor bank is so dimensioned that the power factor can be improved to the optimum possible, even when the

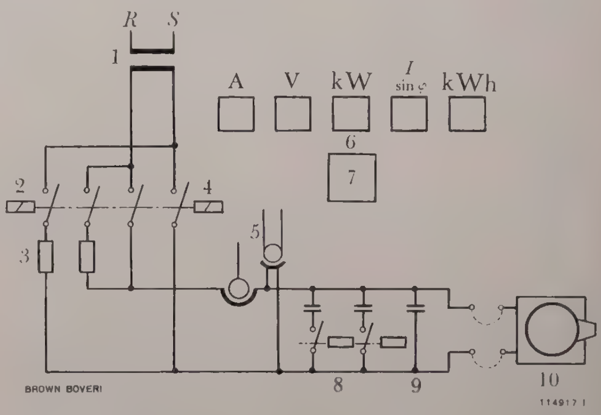


Fig. 3. – Circuit diagram of a mains-frequency crucible induction furnace for single-phase supply

For notation see Fig. 4.

crucible is worn. While the power factor is being matched, the series resistor limits the power input to about half the full value. This reduces the peak load on the mains and prolongs the life of the contacts.

The balancing network distributes the single-phase load evenly between the three phases of the mains. This network comprises a single-phase reactor and an additional capacitor bank. Assuming the power factor is kept at unity with sufficient accuracy at all times, it is sufficient for the balancing network to balance to a fixed rating of about 90 to 100% of the furnace input. This is only adjusted at fairly long intervals, according to the wear on the crucible. This adjustment is effected by reconnecting the appropriate capacitor steps with links. The latter can, if specially requested, be replaced by

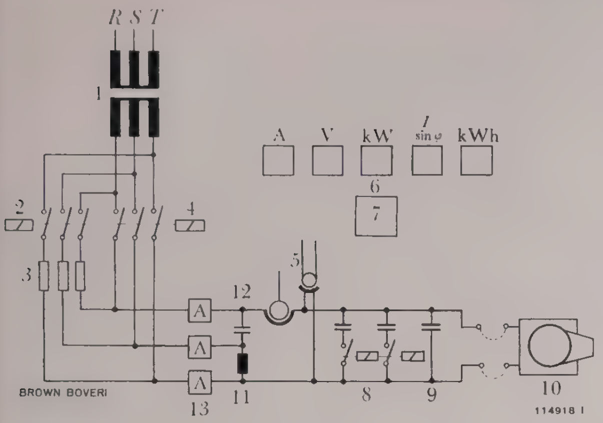


Fig. 4. – Circuit diagram of a mains-frequency crucible induction furnace for three-phase supply with balancing network and parallel capacitor bank for improvement of the power factor to unity

1 = Mains transformer
2 = Starting contactor
3 = Starting resistor
4 = Full-load contactor
5 = Instrument transformer
6 = Instruments
7 = Reactive-power regulator
8 = Switched capacitor stages
9 = Basic capacitor stage
10 = Induction furnace
11 = Balancing reactor
12 = Balancing capacitor bank
13 = Ammeters for balancing phase currents

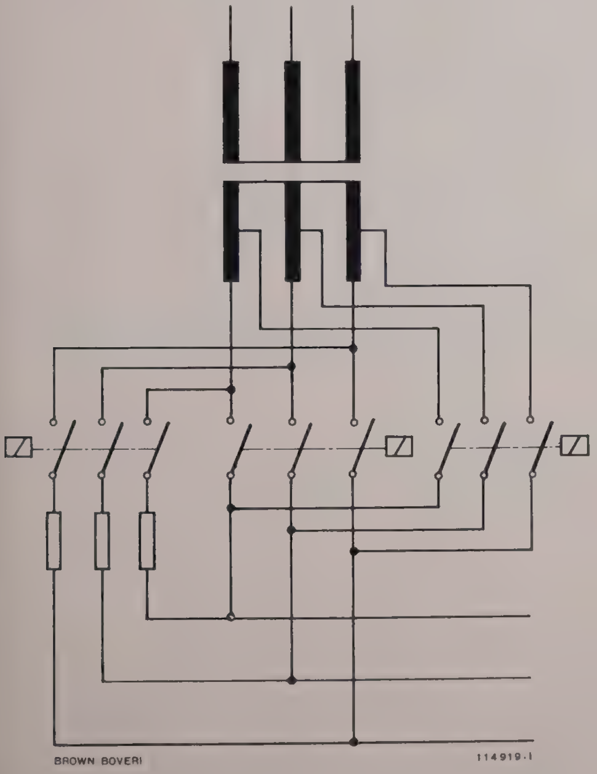


Fig. 5. – Connection of the mains transformer with a secondary tapping for holding, as used for new installations

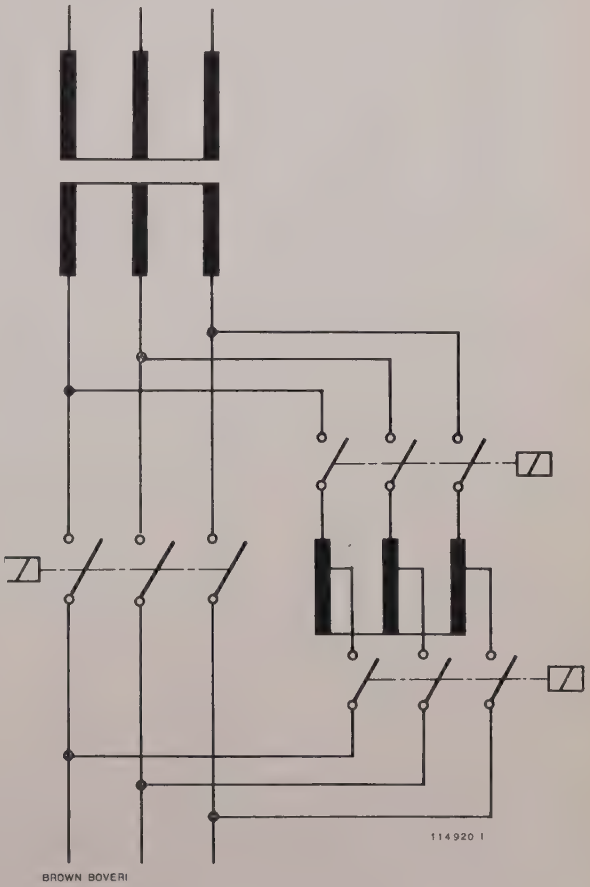


Fig. 6. – Connection of an auxiliary auto-transformer with primary and secondary contactors, used for holding in installations where a mains transformer already exists

TABLE IV

Dimensions in millimetres of distances in Fig. 7 (not binding)

Type ISNG	b_1	h	h_1	h_3	l_4	l_5	l_6
0·8/120	3900	2000	2100	2700	2500	3450	6 200
0·8/320	4300	2000	2100	2700	2500	3950	6 700
1·5/320	4300	2300	2300	2700	3100	3950	7 300
1·5/450	4300	2300	2300	3500	3100	4250	7 600
3·5/450	4300	2750	2700	3500	3700	4250	8 200
3·5/600	4300	2750	2700	3500	3700	4850	8 800
3·5/720	4300	2750	2700	3500	3700	5350	9 300
3·5/800	4500	2750	2700	3500	3700	5350	9 300
4·5/450	4300	3100	3000	3500	3900	4250	8 400
4·5/600	4300	3100	3000	3500	3900	4850	9 000
4·5/800	4500	3100	3000	3500	3900	5350	9 500
4·5/1000	4500	3100	3000	3500	3900	6450	10 600
6/450	4500	3250	3100	3500	4000	4250	8 500
6/600	4500	3250	3100	3500	4000	4850	9 100
6/800	4500	3250	3100	3500	4000	5350	9 600
6/1100	4500	3250	3100	3500	4000	6650	10 900
8/450	4600	3500	3500	3500	4300	4250	8 800
8/800	4600	3500	3500	3500	4300	5350	9 900
8/1400	4600	3500	3500	3500	4300	7450	12 000
12/600	4800	4000	3900	3500	4700	4850	9 800
12/1000	4800	4000	3900	3500	4700	6450	11 400

contactors, which are used to perform the adjustment either under manual control or the automatic control of a balancing regulator.

For furnace ratings up to about 500 kVA a time-lag relay with variable duration of the open and closed periods is sufficient for holding, the heat lost by the crucible being made up by brief power impulses at adjustable intervals. For higher ratings it is preferable to equip the mains transformer with a suitable tapping (Fig. 5) or to provide an auxiliary auto-transformer having primary and secondary contactors (Fig. 6). For high-output furnaces it is advisable to adopt the less expensive solution with power control on the primary side of the mains transformer (Fig. 9).

Layout of the Installation

The layout of a mains-frequency induction melting plant is governed to an appreciable extent by the local conditions and requirements. Fig. 7 and Table IV give some idea of the space required for each of the standardized sizes of furnace, and the amount of equipment involved. In them, every

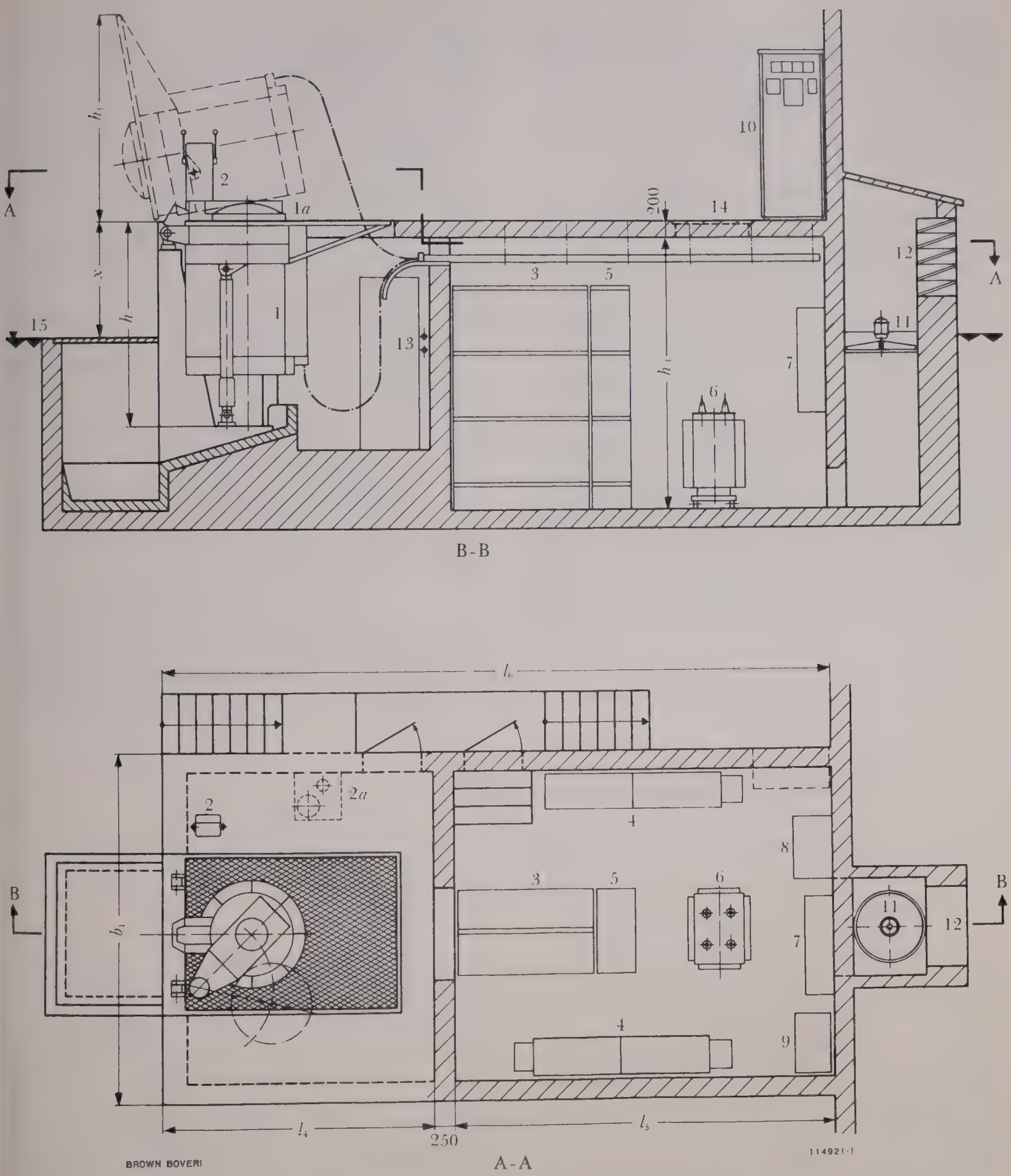


Fig. 7. – Layout of a mains-frequency crucible induction furnace installation

The height x of the platform depends on the method of casting and the size of the ladle.

1 = Induction furnace
1a = Furnace cover
2 = Control desk
2a = Motor-driven pump for pressure oil
3 = Capacitor bank (basic stage)
4 = Capacitors (in steps)
5 = Balancing capacitors
6 = Balancing reactor
7 = Main switchgear
8 = Starting resistor
9 = Auto-transformer for holding
10 = Control panel
11 = Cooling fan
12 = Air filter
13 = Cooling-water pipe
14 = Opening for erection
15 = Foundry floor

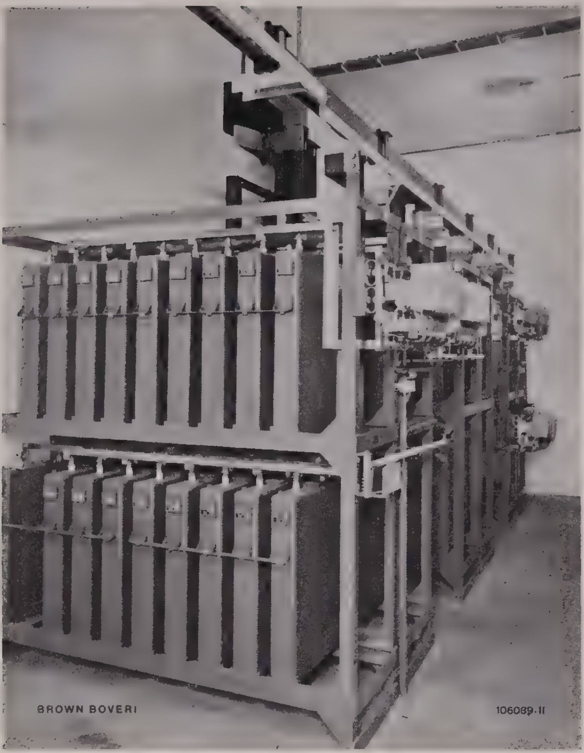


Fig. 8. – Air-cooled capacitor bank rated 2500 kVar, at 500 V, 50 c/s, controlled in stages by contactors, for improving the power factor to unity

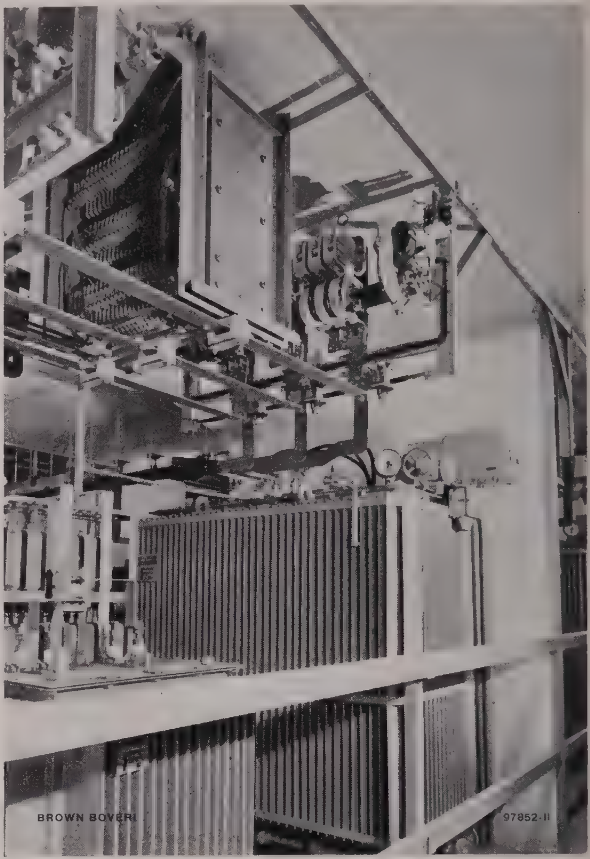


Fig. 9. – The 10-kV regulating transformer, 1250 kVA, with built-in primary tap changer for remote control, as used with a 4·5-t induction furnace

On the left is the balancing network comprising the reactor and capacitors. Mounted on the ceiling are the starting and full-load contactors, and the starting resistor.

effort has been made to keep the leads short, having regard to the overall efficiency, at the same time making the most of the available space with maximum accessibility to the parts of the installation.

Economic Employment of Mains-Frequency Induction Furnaces in Foundries

In many cases the foundry requires definite quantities of liquid metal for casting at definite times; in others the quantities or the times, or even both, may be variable within certain limits. If, in addition, a large number of different types of iron have to be melted in continuously varying quantities, the problem of planning can become quite complicated. Some of the most frequently encountered economic problems were studied in detail by Brown Boveri [4]. It was established that it is generally more convenient to keep down to a low capacity but to aim at a high power input. This results in short melting times and low heat losses. During melting in practice the most favourable temperature of the metal is probably just above the melting point. Until the contents of the crucible are completely melted, it is advisable not to increase the temperature, thereby minimizing wear on the lining. This is particularly true with the temperature-sensitive light alloys on account of the associated risk of gas absorption. From the operational point of view this leads to repeated charging at fairly short intervals (see Fig. 11) [3]. The most common arrangements for furnace installations are shown in Fig. 10. Especially for high-power furnaces the variant in Fig. 10d involves a considerable outlay for switchgear and occupies a very large area, and is therefore not an economic proposition for large installations.

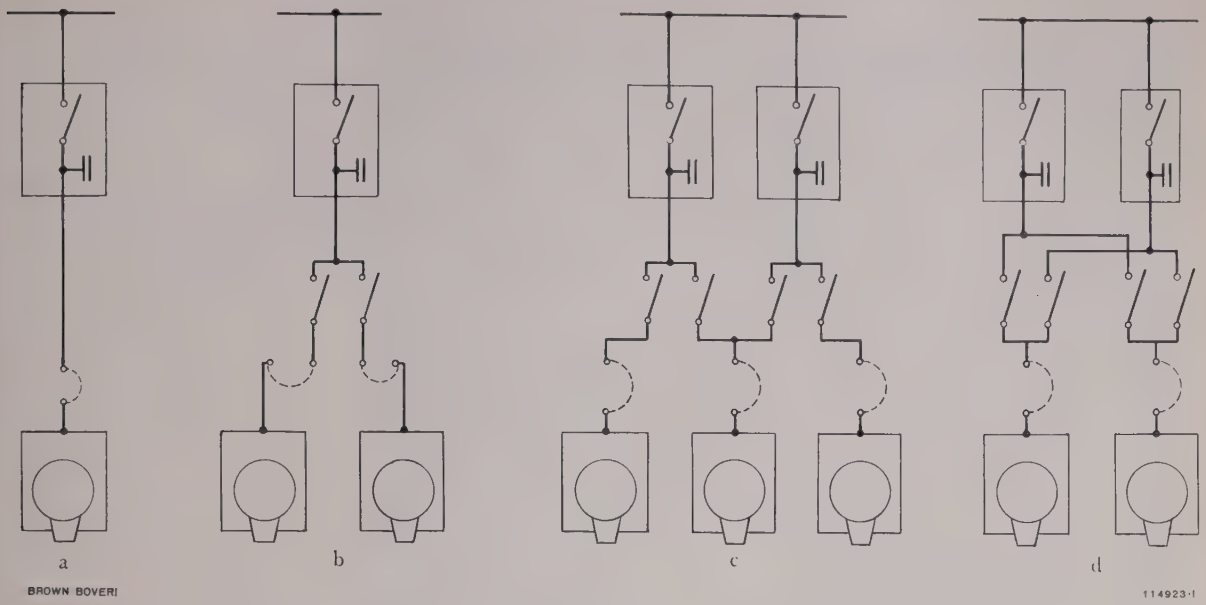


Fig. 10. – The commonest arrangements for mains-frequency crucible induction furnaces

a: Simplest arrangement, comprising one furnace connected via flexible leads to its switchgear.

b: Two furnaces alternately connected via a changeover contactor to one set of switchgear. This arrangement enables a continuous casting machine to be kept supplied with molten metal, without a separate means for holding. Thus the power input can be utilized for almost 100% of the time.

c: Three furnaces selectively connected to two sets of switchgear via links or contactors. Normally two furnaces are in operation, the third in reserve or being relined. This arrangement is often used in large foundries working 24 h a day.

d: Separate sets of switchgear for melting and holding are connected crosswise to two furnaces. This arrangement is very expensive, particularly with high furnace ratings.

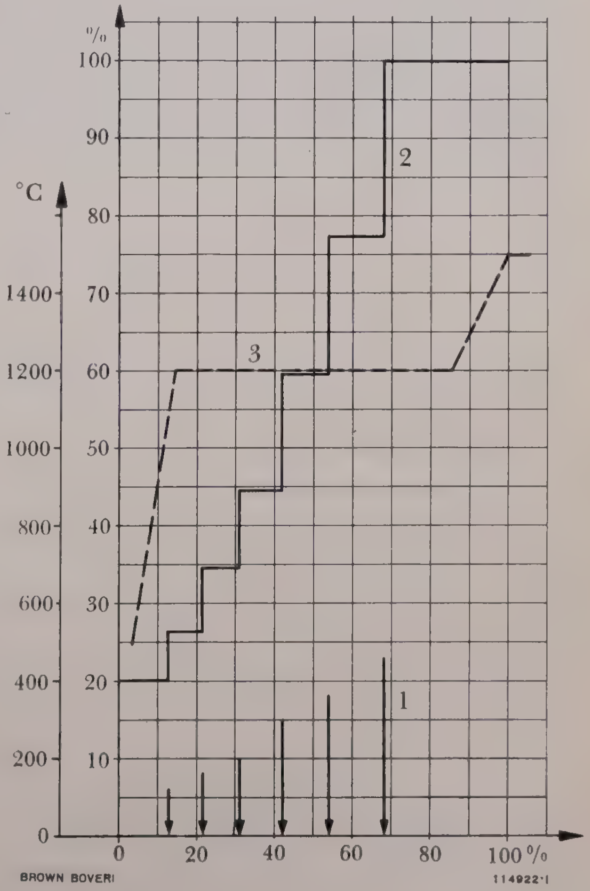


Fig. 11. – Diagram showing how the furnace should be charged in order to maintain a temperature just above melting point throughout the melting process

Subsequent superheating to the pouring temperature with rated power and full furnace lasts only a short time, resulting in a minimum of gas absorption by the melt, and the least wear on the crucible.

Abscissae: Duration of melt-down and superheating as % of the time for a fully charged crucible heated to maximum temperature.

Ordinates: Crucible content and temperature.

1 = Charge weight as % of crucible capacity
2 = Percentage filling of crucible
3 = Temperature of crucible content

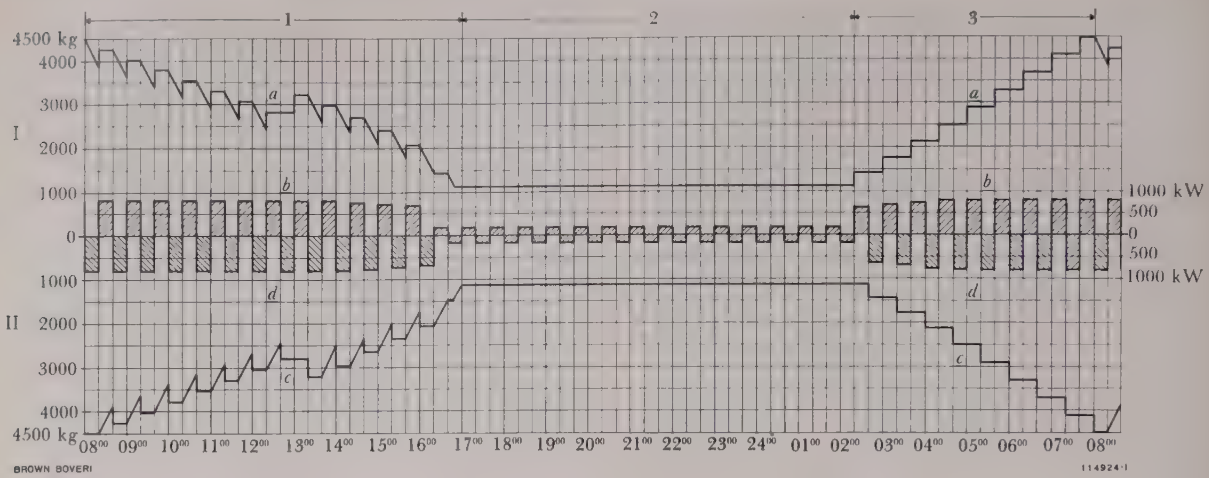


Fig. 12. – The programme of two induction furnaces working alternately

Input 800 kW continuous at 500 V   Total pouring rate per furnace: 1920 kg/h over a period of 8 h

Furnace I: a = Content of crucible in kg
b = Input in kW

Furnace II: c = Content of crucible in kg
d = Input in kW

1 = Melting and pouring   2 = Holding   3 = Melting only

The mains-frequency crucible induction furnace is ideal for melting and finishing grey cast iron. Its favourable properties, both from the metallurgical and from the economic aspect, are most pronounced in this case. The all-electric foundry needs no coke, therefore the stockyard and transport equipment for it is eliminated. Instead, a transformer and the switchgear have to be taken into account. The smelter appreciates the cleaner atmosphere, the improvement in working conditions and simple control of the furnace, which also requires less maintenance. In those places where electric melting is not feasible owing to shortage of power, or unfavourable tariffs, an existing cupola furnace is frequently augmented by a mains-frequency induction furnace acting as heated mixer.

In mechanized foundries there is an almost constant demand for molten metal. Whether one furnace or more are advisable in such cases depends not only on the stipulated hourly output, but also to a considerable extent on the specified number of casts per hour. The furnace installation is well utilized if the casting rate does not exceed 4–5 per hour. If the available charge material is of consistent quality, it is advisable to replenish the furnace with an equal weight of material after each cast. Then, by simply checking the power consumption, which should correspond to the figure obtained experimentally, it is possible to ensure constant pouring temperatures with unchanged analysis. Thus the temperature and analysis only need to be checked at quite long intervals. If part of the content of two or three furnaces is poured in regular succession, the hourly casting rate can be doubled or trebled, without increasing the rate for individual furnaces.

Where casting is stipulated at very short intervals, it may be advantageous to install two furnaces with only one set of switchgear. While one furnace is being used for repeated pouring, and replenishment takes place just before the power is switched on, the other furnace is engaged on melting. Operating in this manner, it is possible to utilize the available electrical input for almost a hundred per cent of the time. If sufficient space is set aside when the plant is first installed, it can later be extended to double the capacity with a correspondingly increased power input. The larger the capacity of each furnace, the easier it is to dispense with a source of power for holding, without any disadvantages from the technical aspect. Without the temperature of the melt dropping unduly, the pauses between successive casts from a 4–5-t furnace may amount to 15–20 min. Fig. 12

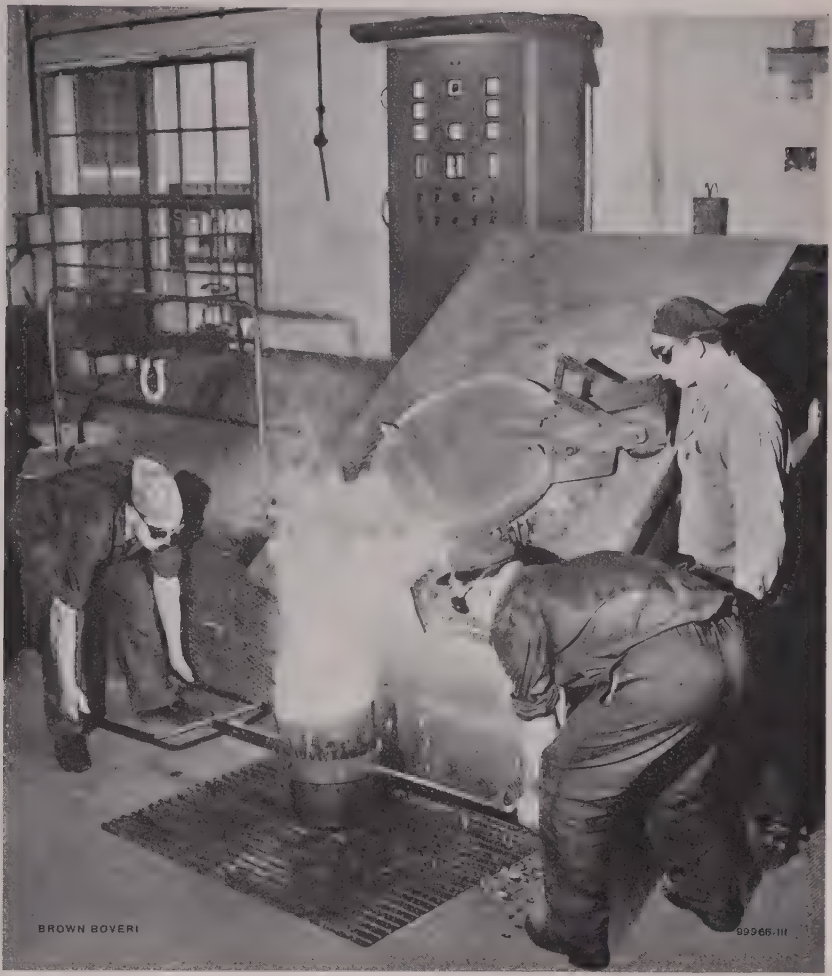


Fig. 13. – 800-kg mains-frequency crucible induction furnace pouring cast steel into a shank ladle

Input 300–350 kW, 380 V, with automatic power factor regulator; hourly melting capacity appr. 400 kg at a pouring temperature of up to 1620 °C.

illustrates graphically the operation of two 4·5-t furnaces melting alternately to produce fittings of malleable cast iron by mechanized casting in single-shift work. Almost half the daily output of this foundry is melted at night while the power is cheap. With this relatively large stock of molten metal it is possible to interrupt melting at peak-load hours and to make good the heat losses of both furnaces with about one fifth of the power required for melting, thus keeping the pouring temperature constant.

The capacity and number of furnaces for a foundry with *intermittent* melting is mainly determined by the normal and peak daily demand for molten metal, the maximum weights of castings and the frequency with which they occur; as well as by the number of changes of alloy in any one day. As soon as the daily demand for molten metal exceeds a certain figure, it will be more economical to install two or more furnaces of the same size, despite the higher outlay compared with a single, very large furnace. With several furnaces it is possible to melt different kinds of metal simultaneously, thus rendering the foundry more versatile and flexible.

Superheating iron in duplex operation is primarily performed in large furnaces. To obtain short superheating times—low heat losses—and sufficient stirring effect to correct the carbon content and bring about rapid alloying, the specific input of the furnace should be sufficiently high. The lining wear is also less because individual melts remain in the crucible for shorter periods.

Mains-frequency induction furnaces can also be used to produce cast steel in an acid crucible. Since the wear on the lining is appreciably greater owing to the higher temperature of the melt, it is preferable to employ smaller units, such as the 800-kg or 1·5-t furnace (Fig. 13). The advantage of the much smaller heat storage compared with arc furnaces, considering single-shift work, is reduced as the size of the furnace grows. Often a medium-frequency furnace is preferred for melting steel when short melting times are desired, because a smaller crucible permits a higher power concentration to be attained with a given throughput. The smaller crucible and the much less vigorous stirring effect permit a basic or neutral lining to be used, if metallurgically needed.

Whenever a new installation is being projected, it is important to investigate which type of furnace, whether a mains or medium-frequency induction or an arc furnace, offers most advantages as regards melting and economics, or whether a combination of different types, as found in numerous modern foundries, is worth considering.

(KME) F. von Burg

Bibliography

[1] F. von Burg: Induktiv beheizte Aluminium-Schmelzöfen. Elektrizitätsverwertung 1959, Vol. 34, No. 6, p. 158–68.

[2] B. Marinçek, VDG, Zürich, and H. Feichtinger, Schaffhausen: Gase im Gusseisen. Giesserei 1959, Vol. 46, No. 18, p. 497.

[3] K. Brokmeier, VDG, Dortmund: Die Bedeutung der Induktionsöfen in der Giesserei. Giesserei 1959, Vol. 46, No. 6, p. 129–36.

[4] K. Brokmeier and W. Lang, Dortmund: Wirtschaftlichkeitsbetrachtungen beim induktiven Schmelzen von Gusseisen und Stahl. Giesserei 1958, Vol. 45, No. 17, p. 465–9.

TEMPERATURE DROP IN CRUCIBLE INDUCTION FURNACES DURING SUPPLY INTERRUPTIONS AND POURING

621.365.5

This article deals with two typical operational conditions encountered in foundries. Failure of the supply must always be allowed for; here the author shows for what length of time a crucible induction furnace may remain without current before the melt solidifies. In automatic foundries a constant supply of molten iron at nearly constant temperature must be available during working hours. With simplified assumptions, equations and curves are derived from which the temperature drop of the melt during pouring can be easily determined. The results then show whether the electrical equipment for one furnace can be dispensed with in installations with several furnaces.

COMPARED with other types of melting furnaces, crucible induction furnaces offer various advantages. The charge can be melted down relatively quickly. To obtain a desired alloy, the individual ingredients can be accurately pre-determined; if they are added shortly before superheating to the pouring temperature, the loss by oxidization of these elements is very small. Even when the melt stands in the furnace the losses are almost negligible. Owing to the relatively vigorous movement of the melt the various additives are absorbed quite rapidly. A laborious, long-winded process of carburizing, of cast iron for instance, is unknown with induction furnaces, provided the electrical input is more than just sufficient for making good the heat losses. The vigorous stirring motion mixes the melt thoroughly, producing a homogeneous cast. If the furnace is emptied in small portions, each casting—from the first to the last—has practically the same analysis. Owing to the small surface area of the melt in relation to the volume of the furnace, which is usually covered with a lid, the smelter is protected against unpleasant radiation. Modern induction melting installations are equipped with automatic power factor regulation, enabling the smelter to devote his full attention to charging the furnace and supervising the melt.

The slag covering the surface of the melt remains at a slightly lower temperature than the rest of the bath because it only receives its heat from the latter. For this reason slagging, as for arc furnaces where the slag is more strongly heated than the bath by the arc, is almost impracticable in induction furnaces. The charge must therefore not contain any undesired impurities; for this reason the induction furnace is employed almost exclusively for remelting.

How greatly induction furnaces are appreciated in modern foundries, and in demand, is clearly borne out by the fact that the Company has at the moment orders on hand for about 30 with capacities ranging from 15 kg to 8 tons, referred to cast iron.

Heat Lost by Full Furnace on Interruption of the Supply

For certain operational eventualities, e.g. when the mains supply unexpectedly fails, it is important to know the drop in temperature of the full furnace as a function of time in order to be able to estimate by what time at the latest the furnace must be emptied, so as to prevent the melt from solidifying in the crucible. It is assumed that the supply of cooling water for the induction coil is not affected by the power failure. Otherwise the insulation of the coil would be damaged by the heat stored in the crucible, even if the furnace were poured immediately.

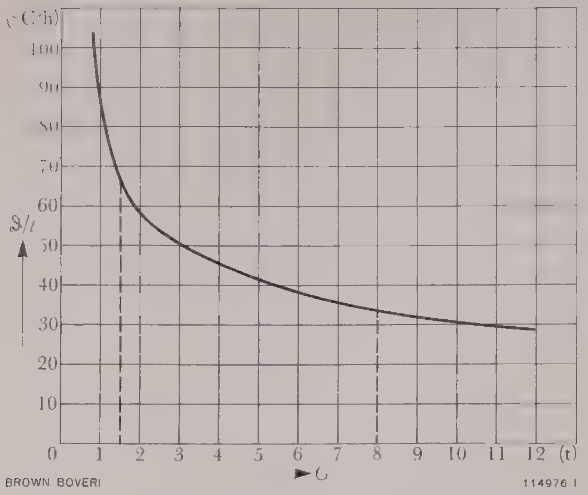


Fig. 1. – Temperature drop per hour of a full induction furnace for cast iron, as a function of the rated capacity, due to interruptions of the supply

ϑ = Temperature drop of the melt in °C
t = Time in h
G = Furnace capacity in tons of cast iron

This drop in temperature can be calculated from the following simple equation:

$$\vartheta = \frac{W_v t}{G c_g + G_s c_s} \qquad (1)$$

In this and subsequent equations the notation is as follows:

G = Weight of the melt with full crucible (kg)
G_t = Weight of melt at time t when poured continuously (kg)
G_s = Weight of the rammed crucible and its insulation, converted in the ratio of its mean temperature to the temperature of the melt (kg)
c_g = Specific heat of the melt (kWh/kg °C)
c_s = Specific heat of the rammed crucible and its insulation (kWh/kg °C)
t = Time (h)
T = Time taken to pour the complete melt, assuming a continuous, uniform pouring rate (h)
$D = G/T$ = Throughput (kg/h)
W_v = Heat lost by furnace at normal pouring
ϑ = Temperature drop of the melt (°C)

The above equation (1) is applicable on condition that ϑ is very small in proportion to the temperature of the bath. This drop increases in proportion to the time t and in Fig. 1 is plotted for an interruption of $t = 1$ h for different sizes of furnace.

Suppose a 1·5-t furnace has a temperature of 1500 °C at the moment the supply fails. We have to determine by what time at the latest the furnace must be emptied, or in other words how long the supply interruption may last, if the melt is not to solidify in the crucible. The temperature of the melt may therefore only drop from 1500 to 1200 °C, i.e. by 300 °C; according to Fig. 1 $\vartheta/t = 66$ °C/h. Hence the desired maximum duration of the interruption is

$$t = 300/66 = 4{\cdot}55 \text{ h}$$

For the same temperature conditions with an 8-t furnace, see Fig. 1, the permissible duration of the interruption works out at 9·1 h. From this it is apparent that induction furnaces can withstand quite long supply interruptions without the melt solidifying, provided of course failure does not occur during melting down, i.e. just after introducing a fairly large solid charge.

Temperature Drop During Pouring

In automatic foundries, e.g. malleable-iron foundries, a continuous supply of molten iron at nearly constant temperature must be available. A melting plant of this kind can conveniently consist of two or more induction furnaces, one of which has reached the desired pouring temperature, while the other furnace or furnaces are engaged on melting down. Depending on the admissible temperature range for pouring, it is possible to leave the furnace switched off during the whole pouring operation. By this means, as shown in Fig. 2, the electrical equipment for one furnace can be dispensed with. If, before the last batch is poured, the temperature of the furnace drops below the minimum permissible figure, that furnace must be switched on again for a short while and superheated.

When planning such furnace installations it is necessary to know the temperature drop in a furnace which is switched off during pouring. Without unduly affecting the results of the calculation of this temperature drop, it is permissible to make the following simplifications: the furnace losses which bring about the drop in temperature are assumed to be constant. In view of the temperature, which may only drop by a few per cent, on account of the quality of the cast, this is admissible. The majority of the heat lost flows from the molten metal to the water-cooled coil. During pouring, the area of crucible surface covered by molten metal decreases, thus reducing the furnace losses. But this is partly counteracted by intense radiation from the surface of the melt to the exposed crucible wall. The remainder can be treated as a welcome safety margin for the calculation. It is assumed that pouring takes place at a continuous, uniform rate, from full to empty crucible. The result is practically unchanged if equal quantities are poured at regular intervals instead.

Since, for the operational condition under discussion, the furnace is fitted with a tightly fitting lid, the losses are mainly determined by the quality and thickness of the refractory material of the crucible, as well as the thickness and nature of the thermal insulation between the rammed crucible and the water-cooled coil. This insulation is in most cases asbestos. The overall thickness of the crucible cannot be increased beyond a certain limit, having regard to the electrical efficiency of the furnace and the size of the capacitor bank required to improve the power factor to unity. To keep furnace losses low, thereby attaining a good thermal efficiency for the furnace, the asbestos insulation ought to be as thick as possible. The limit is imposed, on the one hand, by the stability of the asbestos at elevated temperature and, on the other, by the stipulation that the outer layer of the crucible must not be allowed to sinter, i.e. heated to too high a temperature, on account of the risk of the crucible cracking due to the formation of fissures right through to the asbestos when the crucible cools. Thus, for a furnace of a certain size, the heat losses are fixed within certain limits.

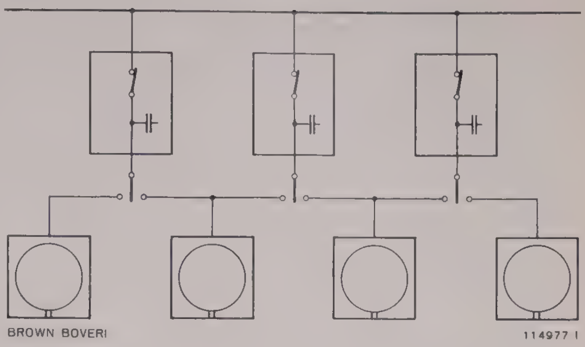


Fig. 2. – Layout of an induction furnace plant with four furnaces and three sets of electrical equipment

One furnace is successively ready for pouring. During this process it is disconnected from the mains.

For calculation of the drop in temperature it is assumed that, at time *t*, the amount of heat dissipated by the furnace equals the reduction in the heat contents of the melt and crucible; in other words

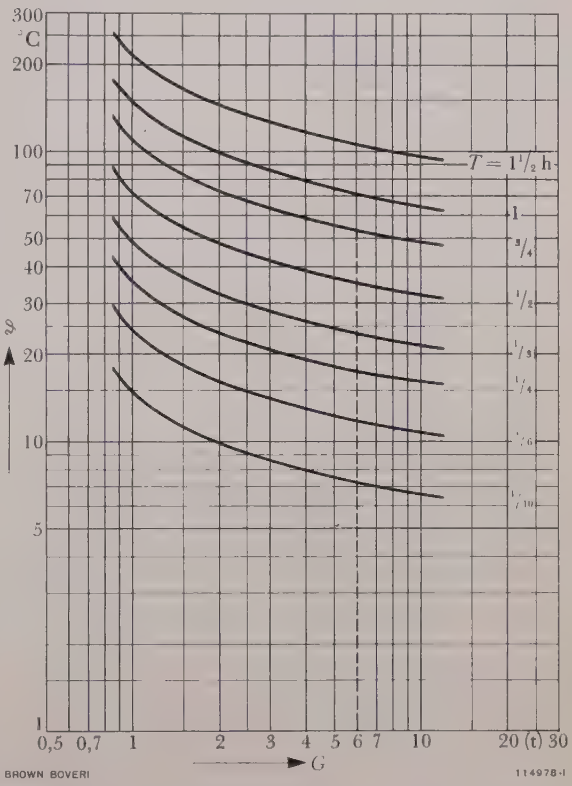


Fig. 3. – Temperature drop in the last batch poured from an induction furnace for cast iron, in terms of the rated capacity and the total pouring time

ϑ = Temperature drop in °C
G = Furnace capacity in tons of cast iron
T = Total pouring time in h

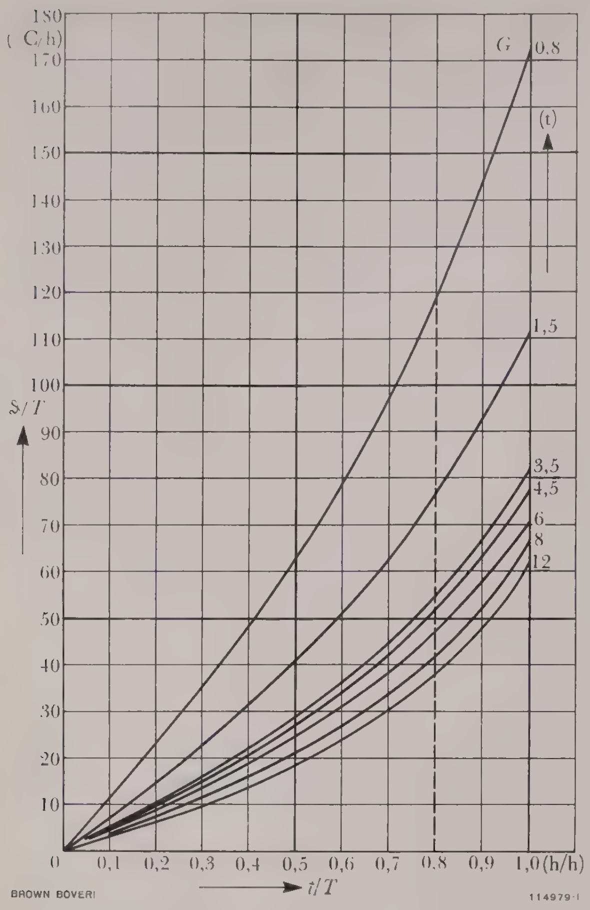


Fig. 4. – Temperature drop of the melt in an induction furnace for cast iron, in terms of the pouring time t, the total pouring time T and the rated capacity

ϑ = Temperature drop in °C
t = Time in h
T = Total pouring time in h
G = Rated capacity in tons of cast iron

$$W_v \cdot \mathrm{d}t = G_t \cdot c_g \cdot \mathrm{d}\vartheta + G_s \cdot c_s \cdot \mathrm{d}\vartheta \qquad (2)$$

$$= [(G - D \cdot t) \cdot c_g + G_s \cdot c_s] \cdot \mathrm{d}\vartheta$$

$$= \left(G \cdot c_g + G_s \cdot c_s - G \cdot c_g \cdot \frac{t}{T}\right) \cdot \mathrm{d}\vartheta$$

$$\mathrm{d}\vartheta = \frac{W_v \cdot \mathrm{d}t}{G \cdot c_g + G_s \cdot c_s - G \cdot c_g \cdot \dfrac{t}{T}}$$

$$= \frac{W_v}{G \cdot c_g} \cdot T \cdot \frac{\mathrm{d}t}{\dfrac{G \cdot c_g + G_s \cdot c_s}{G \cdot c_g} \cdot T - t}$$

By integration between the limits $t = 0$ and t, the temperature drop becomes

$$\vartheta = \frac{W_v}{G \cdot c_g} \cdot T \cdot \int_0^t \frac{\mathrm{d}t}{\dfrac{G \cdot c_g + G_s \cdot c_s}{G \cdot c_g} \cdot T - t}$$

$$= -\frac{W_v}{G \cdot c_g} \cdot T \left| \log_e \left[\left(1 + \frac{G_s \cdot c_s}{G \cdot c_g}\right) \cdot T - t\right] \right|_0^t$$

$$= \frac{W_v}{G \cdot c_g} \cdot T \cdot \left\{ \log_e \left(1 + \frac{G_s \cdot c_s}{G \cdot c_g}\right) \cdot T - \log_e \left[\left(1 + \frac{G_s \cdot c_s}{G \cdot c_g}\right) \cdot T - t\right] \right\}$$

$$\vartheta = \frac{W_v}{G \cdot c_g} \cdot T \cdot \log_e \cdot \frac{1 + \dfrac{G_s \cdot c_s}{G \cdot c_g}}{1 + \dfrac{G_s \cdot c_s}{G \cdot c_g} - \dfrac{t}{T}} \qquad (3)$$

The last batch is poured at the time $t = T$, when the temperature drop is

$$\vartheta_T = \frac{W_v}{G \cdot c_g} \cdot T \cdot \log_e \left(1 + \frac{G \cdot c_g}{G_s \cdot c_s}\right) \qquad (4)$$

From this equation it is evident that, for a given size of furnace, the drop in temperature of the last batch to be poured is directly proportional to the total pouring time. If the crucible has a large heat storage capacity, this reduces the temperature drop. Fig. 3 shows the temperature drop of induction furnaces for cast iron as a function of the size of the furnace, for different total pouring times T. For example, with a 6-t induction furnace, the drop in temperature of the last batch, for a total pouring time of $T = 3/4$ h, is about 53 °C, which in many cases is permissible.

Fig. 4 shows the drop in temperature for furnaces of various sizes while pouring cast iron. From these curves it can be seen that the temperature drops more rapidly the emptier the crucible becomes. Considering the 6-t furnace again as an example, with a total pouring time of $T = 1{\cdot}5$ h, we desire to know how far the temperature has dropped after 1·2 h. Thus we obtain

$$\frac{t}{T} = \frac{1{\cdot}2}{1{\cdot}5} = 0{\cdot}8$$

and from Fig. 4

$$\frac{\vartheta}{T} = 47{\cdot}5 \ ^\circ\mathrm{C/h}$$

Hence at this time the temperature of the melt has dropped by

$$\vartheta = \frac{\vartheta}{T} \cdot T = 47{\cdot}5 \times 1{\cdot}5 = 71\ °\mathrm{C}$$

For an 0·8-t furnace the same temperature drop is attained when 80% of the furnace content has been poured, when the total pouring time is

$$T = \frac{71}{118} = 0{\cdot}6\ \mathrm{h}$$

and the time to pour 80%

$$t = 0{\cdot}8 \times 0{\cdot}6 = 0{\cdot}48\ \mathrm{h}$$

Thus with a 0·8-t furnace the temperature drops 2·5 times as quickly as with a 6-t furnace.

Conclusion

Fig. 1, 3 and 4 show that the crucible induction melting furnaces with a rated capacity of 3·5 t of cast iron, or more, have a relatively high heat storage capacity, compared with their losses. As a result of this property, a supply interruption may last several hours before a full furnace, which was at the pouring temperature at the moment the supply failed, solidifies. For the same reason, it is possible to continuously pour some or all the melt with the furnace switched off and this, under certain circumstances, allows one set of electrical equipment to be dispensed with in installations comprising two or more furnaces.

(KME) W. BRÜGGER

PROJECTION WELDING, A MODERN METHOD OF JOINING METAL PARTS

621.791.763.1

Projection welding is a modern, economical form of spot welding which may be used for joining stamped, drawn or pressed steel parts. A feature is the simultaneous execution of a number of spot welds, the position of individual joints being dictated by the workpiece itself. The present article briefly describes the process and the machines employed, giving useful hints regarding their application and quoting practical examples.

FOR THE mass production of products of the sheet-metal industry, e.g. in the production of accessories for the engineering, electrical and automobile industries, or the manufacture of steel furniture, there is a marked trend towards the execution of multiple spot welds. A process for doing this, which has lately gained steadily in popularity, is projection welding. The difference between this process and ordinary spot welding is that, as shown in Fig. 1, the current concentration required to heat the weld is not carried by a pair of slender electrodes placed against the outsides of the parts being joined, but by projections of the same size in one of the two parts. A notable point of every projection weld is that the path of the current and the welded cross-

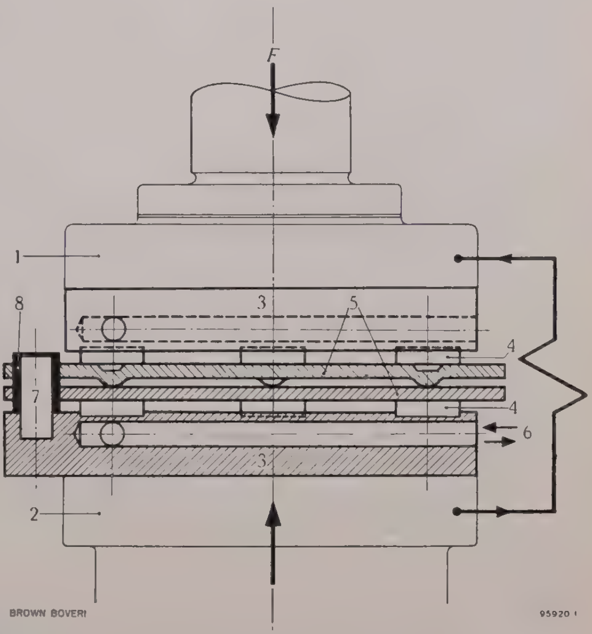


Fig. 1. – Illustrating the principle of projection welding

1 = Upper clamping plate
2 = Lower clamping plate
3 = Body of the electrode
4 = Large electrode inserts
5 = Parts to be welded
6 = Cooling water
7 = Centering pin
8 = Insulation against shunting
F = Electrode force

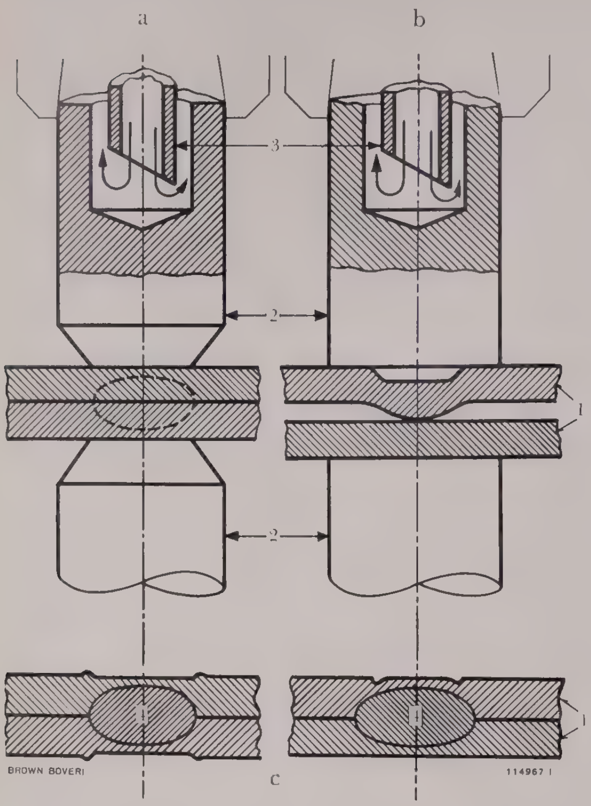


Fig. 2. – Comparison between spot and projection welding

a: Spot weld } before welding
b: Projection weld } before welding
c: After welding

With projection welding, the position of the weld, the path of the current and its concentration are determined by the parts to be welded and not by the area covered by the electrodes.

Whereas spot welding usually produces impressions and bulges on both sides, surrounding the spot, one side of a projection weld remains perfectly smooth. Only on the outside are the typical ring marks visible, and these never project above the surface of the metal.

1 = Parts to be welded
2 = Electrodes
3 = Tube carrying cooling water to tip of electrode
4 = Weld nugget

section are determined by the shape of the part being welded and not by the shape and size of the electrode surface. This leads to the marked advantage that, by using a pair of parallel plate electrodes, it is possible to produce a number of spot welds in one movement, according to the number of projections. The position of the various welds is therefore pre-determined by the projections.

The process of producing the actual joint, like ordinary spot welding, is a pressure weld, for which the quality of the joint and the working range of the machine used are primarily governed by the main variables, electrode force, welding current and time. When these quantities are correctly selected, the projections are heated uniformly by the passage of current and weld rapidly and dependably with the counterpart, which remains completely flat. Since the electrodes used for projection welding are usually massive and have a large surface area, and are therefore easy to cool, it is even possible to weld parts which were surface-treated before welding, e.g. nickel plated, without them discolouring. The fundamental differences between spot and projection welding are illustrated in Fig. 2.

A special advantage of this process is the small amount of heat developed in the boundary regions, thus reducing the tendency of the workpieces to buckle or lose their shape. Also noteworthy is the uniform strength of all spots owing to the complete absence of shunts for the welding currents through already welded joints. With single-spot welding, on the other hand, especially of closed (e.g. circular) groups of spots, the shunt effect through the spot or spots adjoining the weld is quite appreciable

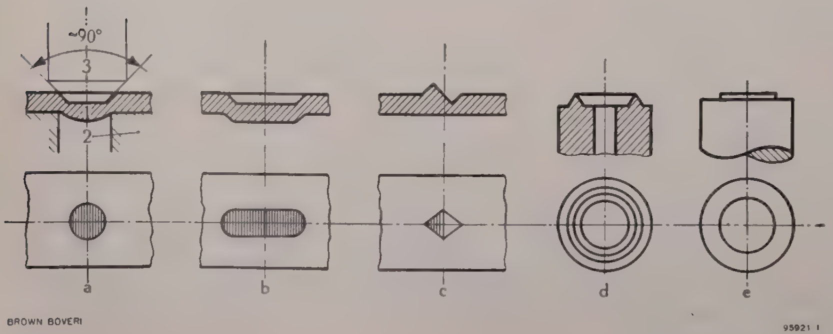
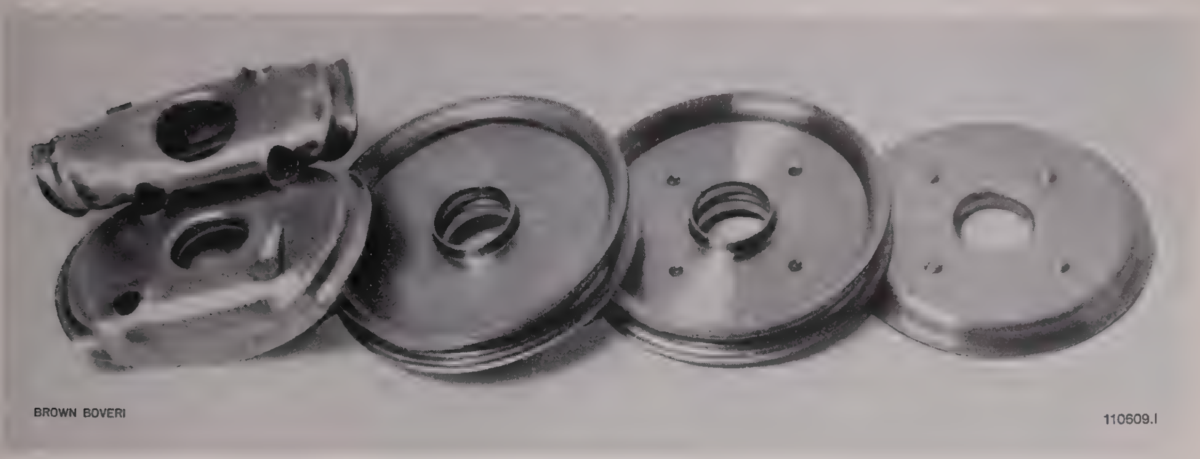


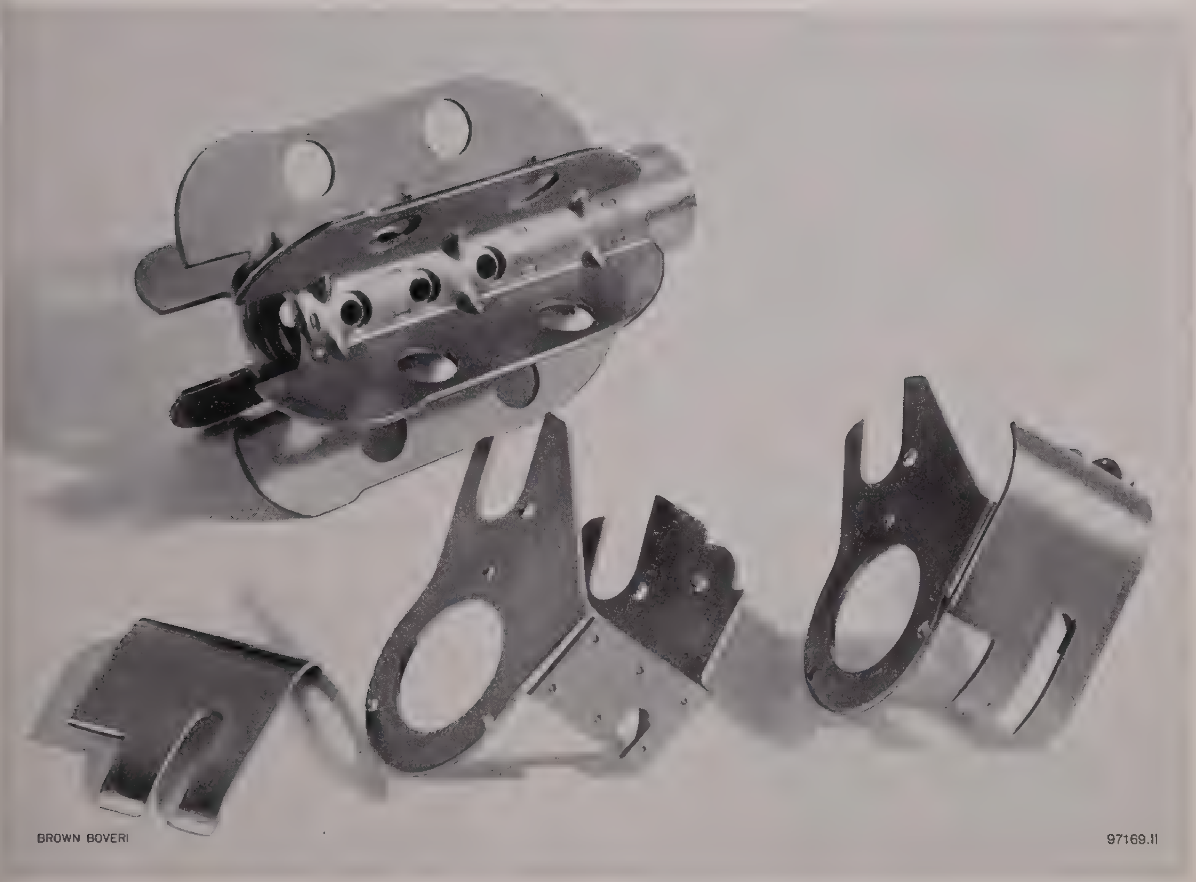
Fig. 3. – Forms of projection commonly used in practice

a: Round
b: Long
c: Pointed
d: Ring
e: Cylindrical

1 = Sheet-metal
2 = Matrix
3 = Simplest form of die



a



b

Fig. 4. – Objects welded with long and round projections

a: Workpieces of this and similar kind can be mass-produced so much more easily and cheaply than with single-spot welding. The peel test on the left shows the high quality of the welds. Most remarkable is the smooth surface of the lower piece after welding. These workpieces can easily be centred by a guide pin on the welding tool. The four round projections are clearly visible on the piece on the extreme right.

b: The position, number and form of the projections are easily recognized.

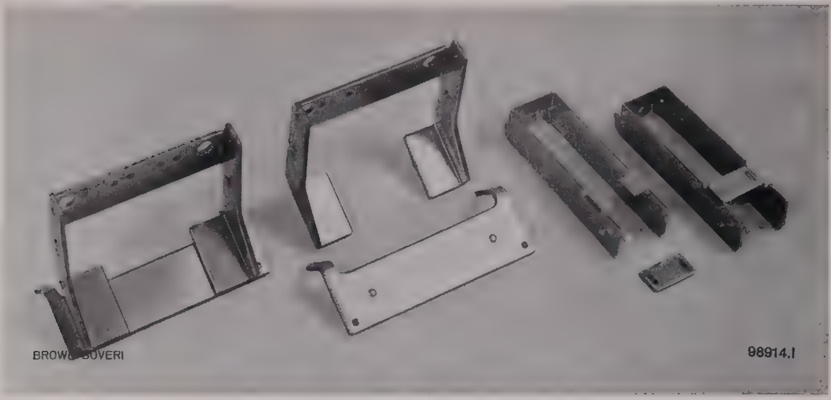


Fig. 5. – Projection welding of nickel-plated parts

Even parts which are plated before welding can be soundly welded without any discolouration at the joints. The risk of corrosion by nickel salts in fissures is eliminated with projection welding, because the surface can be plated before welding. The round and long projections are easily distinguished.

and, by reducing the current, makes itself apparent in the reduction in the size of the spot. With high-powered projection welding machines 20 spots or more can be welded in one stroke, depending on the thickness of the sheet. This process also ensures that the workpieces remain true-to-size.

The shapes of the projections are many and varied. They are governed by the shape and spatial conditions of the workpieces and the strength stipulated for the joint, and must be selected accordingly. The types commonly used in practice are round, long, pointed, ring and cylindrical (see Fig. 3).

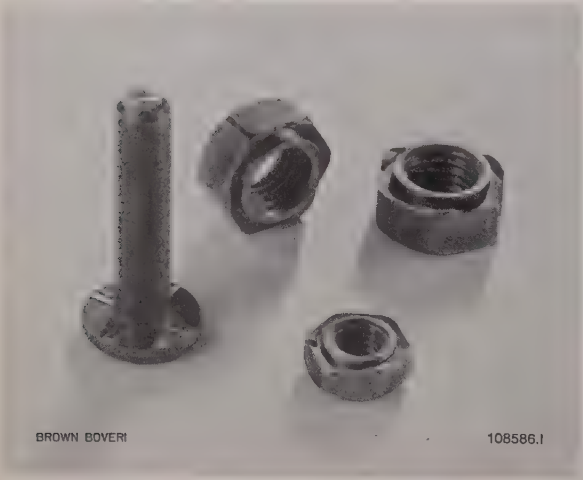


Fig. 6. – Special shapes of projections

The flange pin on the left has cross projections pressed in during manufacture. When such parts are welded to links, cross-bars, etc., with holes, these projections render excellent service. On the right are various "Verbus" welding nuts with the three characteristic projections and the cylindrical neck for centering the nut in a stamped or drilled hole in the counterpart.

Round and long projection, as used for the objects in Fig. 4 and 5, are the shapes most frequently employed, whereas the pointed projection is only used for unimportant joints which are not severely stressed. The cylindrical and ring projections are used for welding pins or studs; in the latter case, which is used where very high strength is required, the projection is slightly tapered, undercut or convex. Cross projections, as shown in Fig. 6, are used for welding flange pins in position. Fig. 7 depicts stud welds of high quality (cylindrical projection). All parts were case-hardened before welding.

There is usually no need for a special process to make the projections in the workpieces. If the tools are suitably designed, the projections can be produced simultaneously by a preceding bending, stamping or embossing action. A point which demands close attention is the maintenance of equal height in the projections, in order that they make proper contact with the counterpart; this is essential for the projection of uniform, high-grade welds. It is of course important, too for all points to have about the same contact resistance. As for spot welding, the parts to be joined should be free from scale, rust, paint, dirt, etc. When joining parts of different thickness, it is preferable for the projections to be in the thicker of the two. This prevents the projection from being deformed merely by the pressure of the electrode before the current starts to flow.

For low-carbon steels the most favourable depth of the projection is 20–25% of the diameter. An

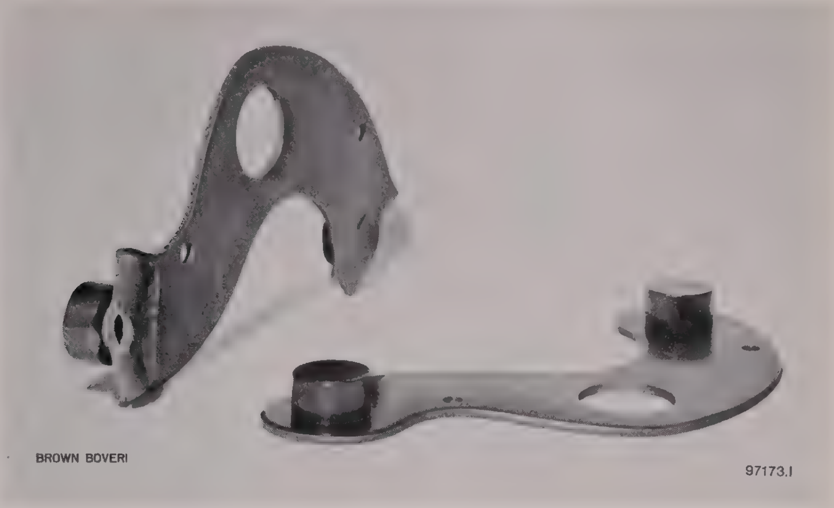


Fig. 7. – Bosses welded on unperforated parts

All parts are case-hardened before welding. The neatly and firmly welded cylindrical bosses are exposed to alternating stresses in service. The peel test on the left is good proof of the strength of the joint.

approximate figure of 17–18 kg/mm^2 may be allowed for the specific welding pressure [1].[1] Due to differences in the composition of the materials to be joined, as well as the wide variety of shapes of workpieces and welding problems, it is advisable to determine the most suitable settings by trial welds. New approximate figures for the dimensions of round projections in deep-drawing sheet are listed in Table I. The curves in Fig. 8a give rough values of the welding current, force and time, whereas Fig. 8b shows the shape of a projection forming tool. The information in Table I was published by the International Institute of Welding (I.I.W.) [2].

Machines and Control

A prerequisite for high-grade welded joints is efficient and purpose-designed equipment. The power a projection welding machine must produce is determined by the maximum thickness of the material containing the projections and the number of spots which have to be welded at one time (sum of the forces and currents). In practice, sheet-steel is welded up to a thickness of 5 mm for a single sheet, for which currents up to 100 kA and electrode forces up to about 5 t are required. The pressure is mainly exerted pneumatically, but in very large units oil pressure is employed. For ratings up to about 200 kVA at a duty cycle of 50% the machines are single-phase, since they then involve less equipment and are therefore cheaper. Owing to the good power factor (small secondary loop because the transformer is installed close to the machine), three-phase supply does not bring advantages to quite the same extent as, for instance, it does with spot welding machines having long arms and a large vertical clearance from the heavy-current conductors (as used in coachworks). Nevertheless for large units with a heavy power consumption, the three-phase arrangement does offer some advantages as regards the power supply, on account of the load being symmetrically distributed between the phases.

In order to perform their duties properly, projection welding machines must comply with the following conditions: The pedestal and arm should not exhibit any measurable distortion and, by ensuring that the clamping plates are always exactly parallel, permit uniform distribution of the total electrode force and welding current between all the projections. The pressure system and medium should be capable of maintaining constant pressure on the workpiece during the whole welding period, and producing a rapidly increasing force. For the work to be performed rapidly, and yet without shock, an automatic means of damping the impact must be provided for the protection of the workpiece and

---

[1] The figures in square brackets refer to the bibliography at the end of the article.

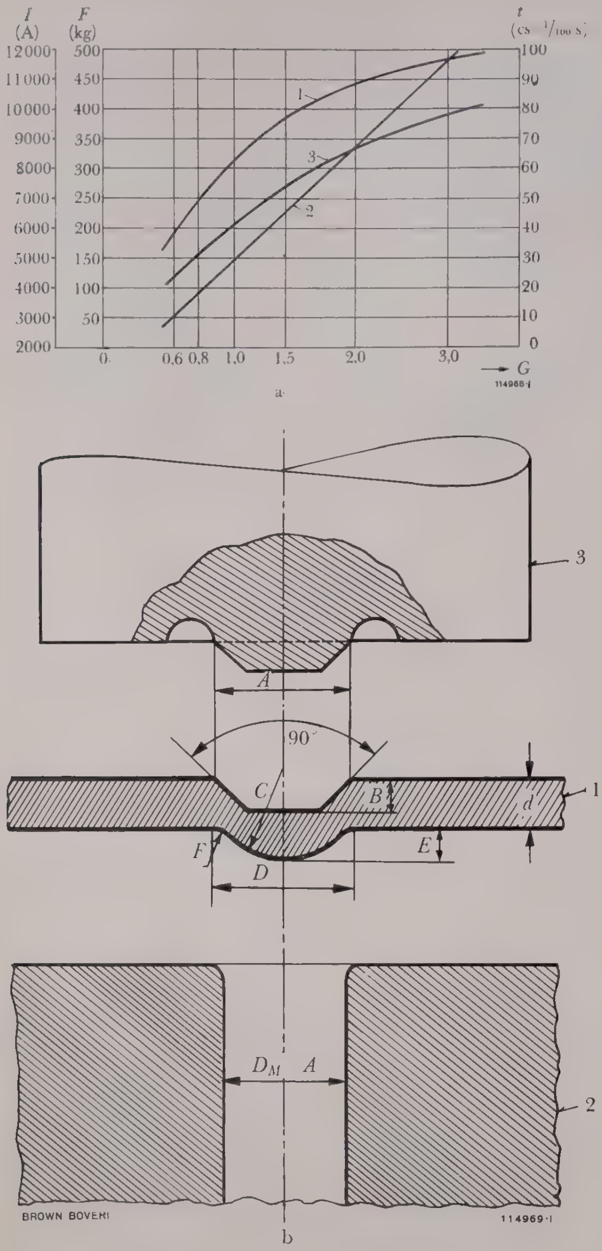


Fig. 8. – Welding with round projections on low-carbon steel sheet

a: Approximate values of current, electrode force and weld time per projection (according to I.I.W.)

G = Size of projection
I = Welding current in A
F = Electrode force in kg
t = Weld time in $^1/_{100}$ s

1 = Welding current 2 = Electrode force 3 = Weld time

b: Dimensions of projection and tool

1 = Sheet 2 = Matrix 3 = Die
D_M = Diameter of matrix bore

Excellent results have been obtained with dies and matrices as illustrated, having the dimensions listed in Table I, particularly with deep-drawing sheet.

TABLE I

Dimensions of projections according to I.I.W.

Sheet thickness mm	Projection size No.	Dimensions in mm				
		A	*B*	*C*	*D*	*E* = *F*
0·52–0·70	0·6	2·58	1·00	1·25	3·00	0·71
0·71–0·96	0·8	3·00	1·12	1·40	3·35	0·80
0·97–1·29	1·0	3·45	1·25	1·60	3·75	0·90
1·30–1·82	1·5	4·00	1·40	1·80	4·25	1·00
1·83–2·46	2·0	4·62	1·60	2·00	4·75	1·12
2·47–3·39	3·0	5·30	1·80	2·24	5·30	1·25

the welding tool. To prevent accidents (hand injuries, etc.) to operators of projection welding machines, which are comparable with heavy presses or stamping machines, they must be equipped with two-handed safety control. This can be conveniently arranged by providing a pair of push-buttons requiring both hands to operate the machine, e.g. for welding small objects.

Projection welds with high quality factors can only be produced when the machine is equipped with synchronous-precision electronic control. Only in this way can the power be continuously controlled and the weld times exactly reproduced, not to mention the control of welding with current and pressure programmes.

For the execution of small projection welding jobs with, say, two to four spots in thin pieces of low-alloy steel, it is often sufficient to use a strong spot welding machine with a short arm projection (Fig. 9). But to be sure of obtaining sound welds, the pressure must be exerted pneumatically and the movement of the upper electrode must be vertical.

When the stipulations regarding the strength of the weld are not unduly severe, and only a small number of spots have to be welded each stroke, the most suitable control units are often ignitron controls for the four times: squeeze time, weld time, hold time and repetition. A technical advantage from the welding aspect is obtained with slope control (also known as modulation), in which the current is increased slowly to its maximum level

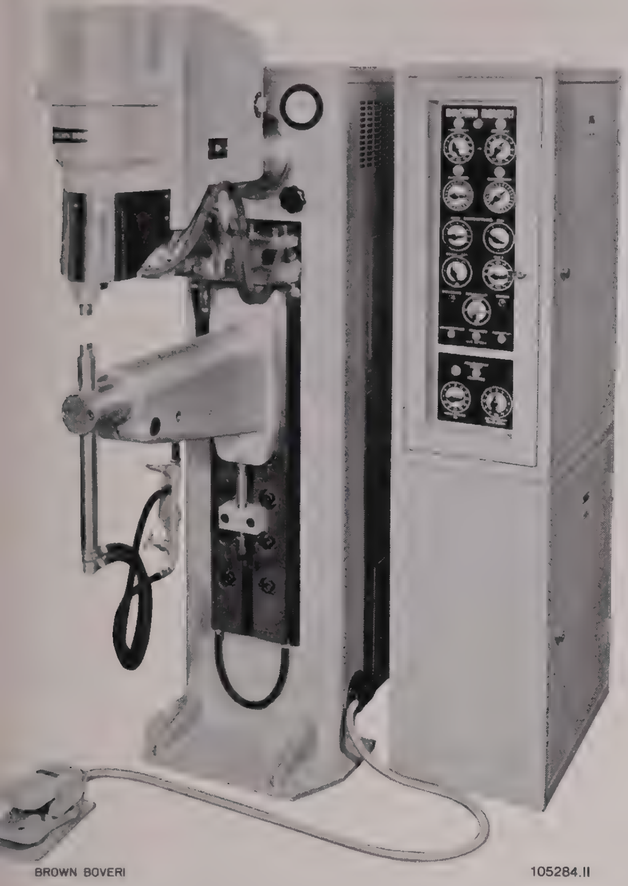


Fig. 9. – Universal, pneumatically operated, electronically controlled spot welding machine

This versatile machine operates with a preliminary and a working stroke, and can be employed for repetition or single spot welds. If the upper, adjustable arm is pushed back to its minimum projection and the spot-welding electrodes are replaced by electrodes suitable for projection welding, the machine is capable of executing quite satisfactory projection welds on small articles. By augmenting the electronic control unit for pulsation, it can be used for welding with single or repeated pulses or, with the necessary additional equipment, for seam welding. With air at a pressure of 6 atm it can develop an electrode force of 600 kg.

(Fig. 10). In this case the low initial current performs the task of preheating to a certain extent, particularly at the peak of the projection, thereby ensuring good contact and current transfer. When welding thicker sheets and larger numbers of spots, small inaccuracies in the preparation of the projections must be taken into account, their detrimental effect being overcome by pulsation welding, where the current is interrupted several times without releasing the pressure. The spacing, individual duration and number of the pulses can be varied according to the requirements. In this way not only are the projections heated less fiercely and evened out, but welding takes place without any spattering (no local overheating). The oscillogram of a pulsating welding current is illustrated in Fig. 11. For welding high-carbon steels the use of pressure and current programmes is recommended. These enable current and electrode force during the welding phase to follow preset values, differing from one another, so that the pressure can be increased during the forge time, and the current can be employed for preheating and post-heating (an annealing effect).

A new development which complies fully with the conditions referred to earlier is the projection welding press illustrated in Fig. 12. Its main features are as follows: The extremely robustly constructed, welded housing of the machine accommodates the single-phase transformer, which itself is notable for its special design and small dimensions. It has Hypersil laminations and is capable of producing a current of about 85 kA and a power output of 225 kVA at 50% duty cycle. Its favourable position near the welding point, and the resultant small secondary loop (throat depth) result in a high power factor of 0·8–0·9, depending on the distance between

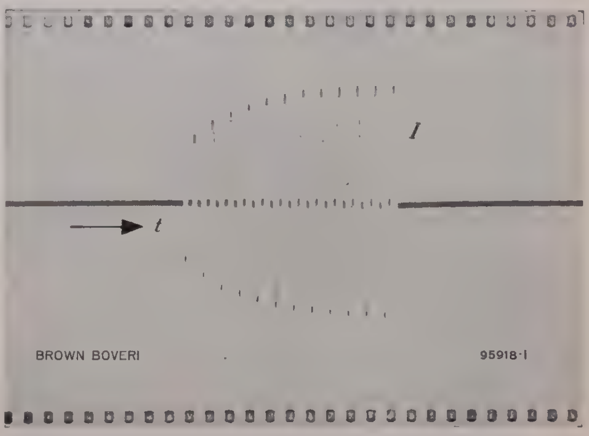
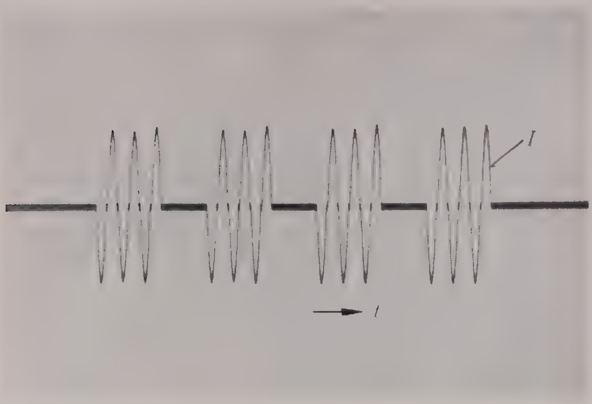


Fig. 10. – Slope control

When welding with slope control the current *I* rises at a variable rate to its maximum. Thus at the beginning of the weld time a smaller amount of heat is generated in the projections, allowing them to even out dimensional inaccuracies before the full current is attained.



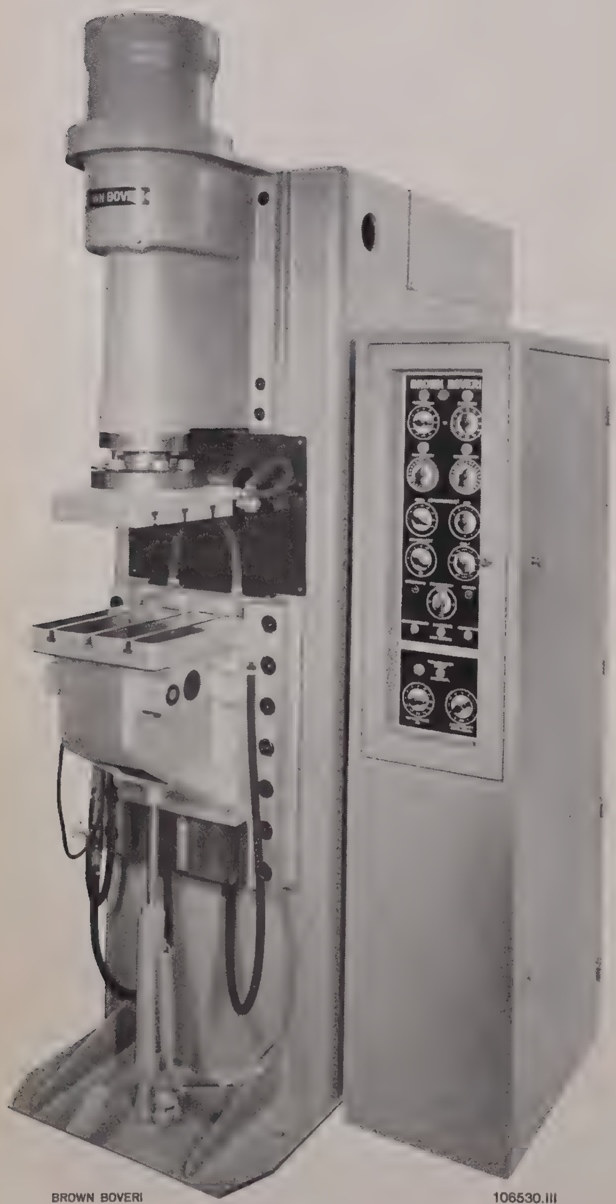
BROWN BOVERI 114970-I

Fig. 11. – Oscillogram of pulsating welding current

Pulsation welding is particularly advantageous with projection welding. It ensures freedom from spatter.

I = Current t = Time

the clamping plates. Mounted on the perfectly rigid projecting arm is the pneumatic operating mechanism of the moving electrode. To extend the working range of the machine it is convenient for this to operate in two pressure ranges on the tandem principle. In range I only one piston is actuated and, depending on the pressure of the incoming air, electrode forces between 400 and 1500 kg can be attained. However, by simply switching over the air flow in the pneumatic system so that it strikes two pistons, it is possible to produce forces between 1500 and 3000 kg. An emergency release and two-handed push-button safety control afford protection to the operator. In conjunction with it the pneumatic system is so designed that the moving electrode remains open or returns to that position if the mains voltage fails (air cushion under the piston), thereby ruling out accidents from this quarter. To protect the welding tool and workpiece this machine also includes the pneumatic damping system fitted to all Brown Boveri high-powered spot welding machines.



BROWN BOVERI 106530.III

Fig. 12. – Pneumatically operated projection welding machine with a wide working range

This very rigidly constructed machine is a new standard design capable of operating in two pressure ranges. According to requirements, electrode forces of 400–1500 kg or 1500–3000 kg can be produced by means of a two-way (tandem) pneumatic system. With a rated input of 225 kVA at 50% duty cycle it produces a maximum welding current of approx. 85 kA. The electronic control, which is preferably installed next to the machine, can control the following functions: Squeezing, welding with or without slope control, holding and repetition. It can also be used for pulsation welding with up to ten pulses, with slope control if desired. The welding current is controlled by varying the phase angle of the firing point of the ignitrons in the unit.

For smaller capacities the Company also makes projection welding machines capable of exerting up to 1500 kg, with an optimum welding current of about 50 kA. The new control unit type PUNZIb used with this machine is a development from the well-tried unit type PUZI, and contains some of the same components. In addition to the four-time programme—squeeze time, weld time, hold time, repetition—it also provides facilities for slope control and power control by varying the phase angle. The latest addition is the device controlling pulsation welding. The principle on which the unit operates is as follows (see Fig. 13).

On expiry of a controlled heating period the unit is ready for operation. Voltage is applied to the electro-pneumatic valve of the machine by a starting contact. The compressed air, at a pressure regulated by a reducing valve, flows into the cylinder and closes the electrodes. As soon as the desired pressure is reached in the cylinder, a pressure relay gives the starting impulse S to the control unit, and the squeeze time regulator Q is set in operation. When the squeeze time (variable between 0·06 and 2 s) has expired, the heat-time regulator W receives an impulse synchronous with the mains voltage. Via the current regulator I, the impulse generator J, the impulse transformer T and the thyratrons V_1 and V_2, this allows the ignitrons Z_1 and Z_2 to fire, and the current flows in accordance with the setting of the current regulator. At the end of the heat time, variable between 0·02 and 2 s, the firing of the ignitrons is blocked, the programme continuing because the cool-time regulator P comes into action. On expiry of the pause time, variable between 0·02 and 1 s, the latter actuates the heat-time regulator W again. This sequence between P and W can continue for any length of time, allowing the control system to be used for seam welding. For projection or spot welding with one or more current pulses the pulse counter C now comes into action. At the end of each heat time the counter C receives an impulse at the same moment as the cool-time regulator P. Depending on the selected number of pulses —from 1 to 10—the counter C causes the programme to advance a stage further after the set number of pulses by applying an impulse to the hold-time regulator N and stopping the heat-time regulator W at the same instant. On expiry of the preset hold time, variable between 0·02 and 10 s, the hold-time regulator N actuates the off-time regulator R, which opens the circuit of the air inlet valve, causing the electrodes to part. With this control system it is also possible to weld with slope control. The rise may take effect only during the first, or during several or all pulses.

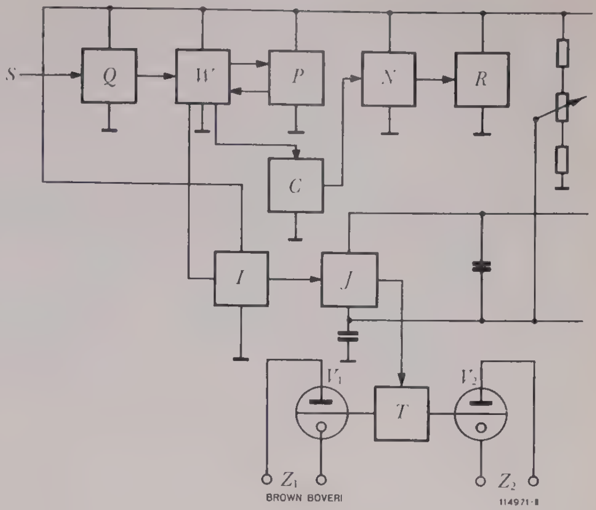


Fig. 13. – Schematic diagram of the type PUNZIb control

S = Starting impulse from the machine
Q = Squeeze-time regulator
W = Heat-time regulator
I = Current regulator
J = Impulse generator
T = Impulse transformers
V_1, V_2 = Thyratrons for firing the ignitrons
Z_1, Z_2 = To the ignitrons
P = Cool-time regulator
C = Pulse counter
N = Hold-time regulator
R = Off-time regulator

Applications for Projection Welding

Projection welding may be employed with advantage when several points have to be welded in a restricted area, or simple mechanical parts, such as pins, bosses, nuts, rings, etc., have to be attached to batch-produced articles quickly, neatly and rationally. A few typical examples will now be described.

In light engineering it is often necessary to join a grooved boss, hub, or ring permanently to a perforated object. In this case ring-projection welding renders invaluable service. The ring projection is formed by the edge of the stamped hole in the counterpart and the bearing surface of the ring, which is chamfered without increasing the production cost of the ring because this can be done at the same time as it is cut out. An important point is that the edge of the hole must only have the burr removed, but must not be countersunk. To make sure the ring is axially centred in the hole, the welding tool can have a centering pin or a cylindrical recess. The working time and labour costs resulting from the adoption of projection welding, for instance a 36 mm o.d. ring to a 4 mm thick plate, are only about one-sixth of those for arc welding, which was previously the usual method.

When the formation of an external swelling round the joint is inadmissible for functional reasons, bosses or hubs are made with a collar (Fig. 14c and 16). By this means not only is a clean joint obtained, but also the workpiece is reliably centred by simple electrodes having no special means of centering. The comparative times and costs of rivetting, arc welding and ring-projection welding such parts are listed in Table II. Compared with rivetting allowance must also be made for the material saving and the increased strength of the joint obtained with projection welding.

In light engineering, e.g. the manufacture of small parts or sheet-metal enclosures, there is an everyday need for detachable joints between two or more parts. This gives rise to the old problem of providing threads in sheet-metal where, to reduce work and costs, the limit of the load capacity of the threads is often exceeded. When thin sheet is involved, it becomes necessary to weld tapped rings or ordinary nuts axially centred with respect to the hole in the

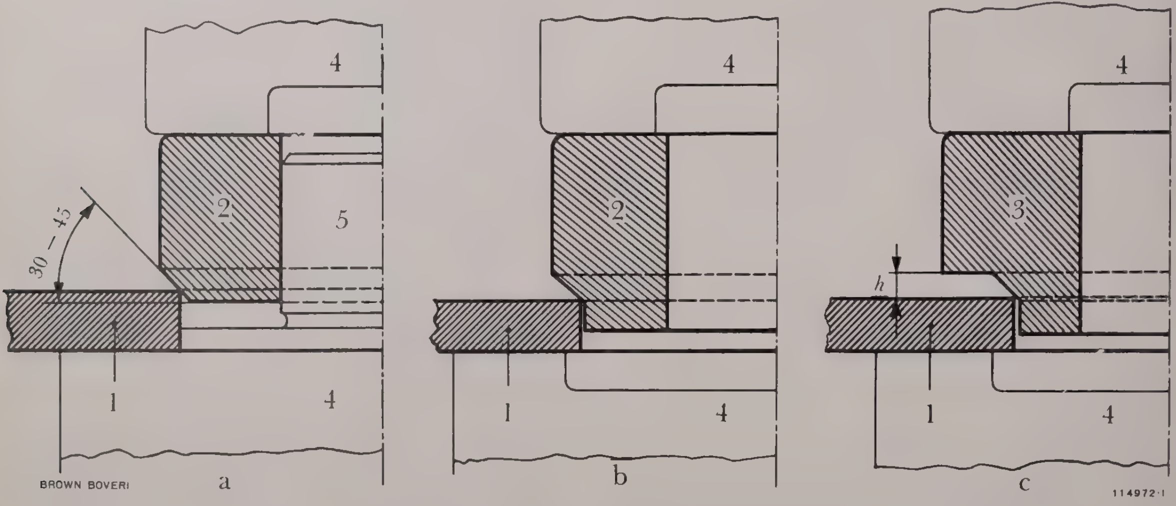


Fig. 14. – Ring-projection welding of bosses

The position of the weld is governed by the chamfer on the ring and the edge of the hole.

a: The axial centering of the ring is assured by a spigot on the tip of the welding tool. To prevent a shunt effect it should be insulated or at least of non-magnetic steel.

b: In this case the ring is centered by a short neck, but this necessitates quite accurate drilling.

c: If the external weld bead is disturbing, bosses and hubs can be made with a collar which ensures that the ring is axially centered. The most suitable height *h* of the chamfer should be determined by trial.

1 = Counterpart
2 = Ring
3 = Hub
4 = Electrodes
5 = Centering spigot
h = Height of chamfer

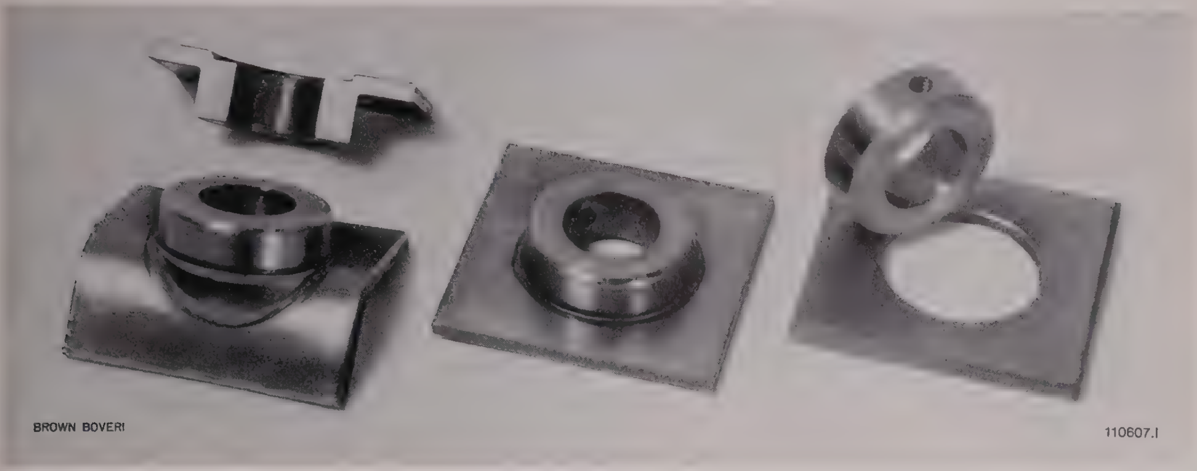


Fig. 15. – An example of ring-projection welding

The neat weld and excellent strength of the joint are obvious at a glance. Free-cutting steels should not be employed for the parts to be welded, on account of their high phosphorous and sulphur content and poor weldability. Approximate figures for welding rings of 37·11 steel with dimensions 36 mm o.d., 20 mm i.d.

Electrode force	1500–1600 kg
Welding current	48–50 kA
Weld time	0·2 s
Forge time	0·1 s
Hold time	0·35 s

sheet. Even in progressive and well-equipped factories the procedure adopted is often the following. The nut to be welded is held in position by a bolt through it and the sheet, the whole being held firm by a counter-nut. When the first nut has been arc-welded to the sheet, the slag must be removed from

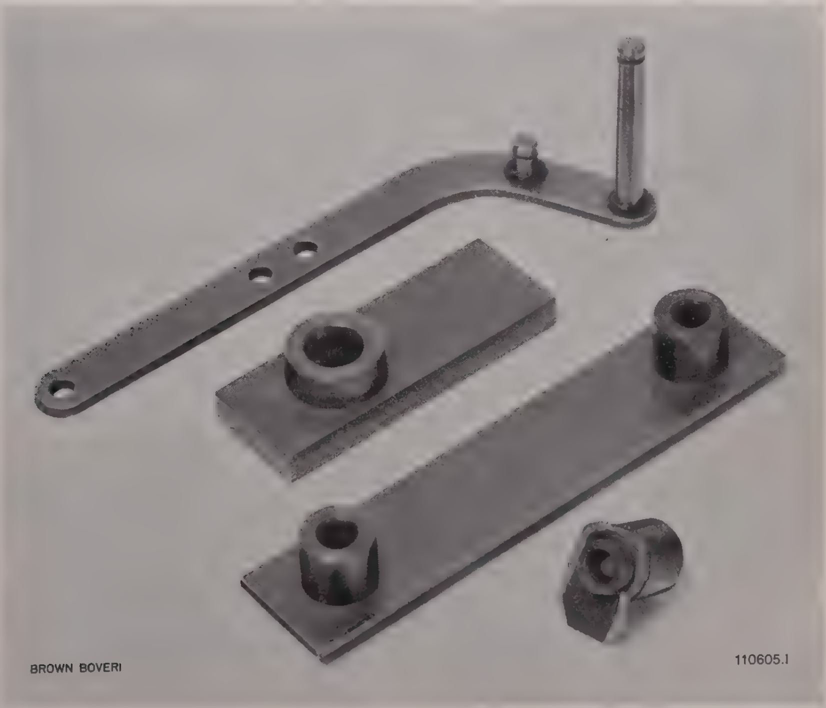


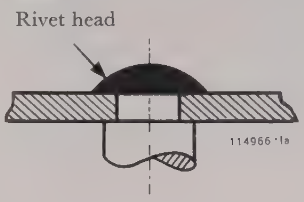
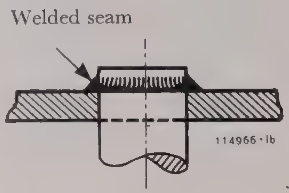
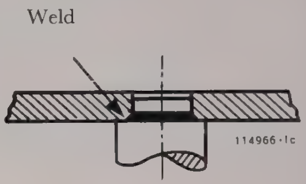
Fig. 16. – Applied ring-projection welds

Note the clean welds and absence of spatter.

TABLE II

Comparison of times and costs

The time and costs (material + labour) for the three processes rivetting, arc welding and projection, indicate the marked advantages of the latter process.

Rivetting in rivetting machine	Arc welding with fixture	Ring-projection welding
		
Time taken to execute 100 operations		
Set working time 0·6 h Setting-up 0·4 h	Set working time 1·2 h Setting-up 0·25 h	Set working time 0·35 h Setting-up 0·25 h
Relative cost per element, including cost of prepared material, considering a quantity of 1000 off		
100%	135%	92%

the seam, and splashes of metal cleaned away from the nut and its surroundings. After unscrewing the lock-nut and bolt thin, plate-shaped workpieces which, to perform their task properly should remain flat, often have to be straightened, possibly too because they have become buckled or distorted during welding. Apart from the unpleasant discoloration of the metal caused by its oxidization at high temperature, the threads of the nut also had to be recut because they had contracted. The time taken in carrying out this work, even when the weld was well prepared and executed by a skilled welder, amounted to 1–2 min or even longer per nut, depending on the size of the nut.

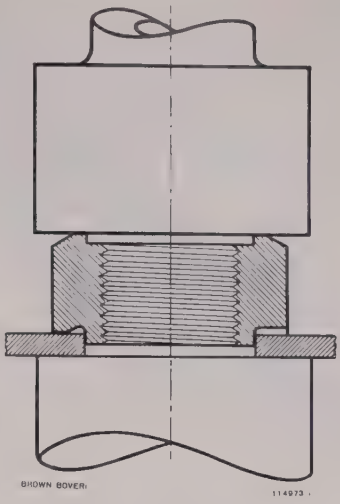
Such welding tasks can be performed much more rationally with special welding nuts. These are steel nuts with a ring-shaped neck, by means of which the nut is centred in the hole. The three small welding projections (see Fig. 6) act as a three-point seating for the nut which, with correct choice of electrode force, current and weld time, is soundly joined to the counterpart. To prevent distortion of the thread and the mouth of the nut, the latter is slightly recessed on the electrode side, thus ruling out the possibility of damage when a flat electrode is used. Fig. 17a shows a section through a "Verbus"[2] welding nut. As a result of the short duration of the welding process, which is not influenced by the skill or personal judgement of the welder when performed in this way, all subsequent treatment is eliminated. The preparations for welding simply involve placing the nuts in position and placing the workpiece between the electrodes. Since the weld time for, say, a M 10 nut amounts to only 0·2 s, the working time for each welded nut is only 10% of that with arc welding. Some interesting applications are illustrated by Fig. 18 and 19. In Fig. 20 approximate values of welding current, electrode force and weld time are plotted for projection welding M 4–M 16 "Verbus" nuts with pneumatically operated Brown Boveri machines. These figures were determined in collaboration with Messrs. Bauer & Schaurte.

---

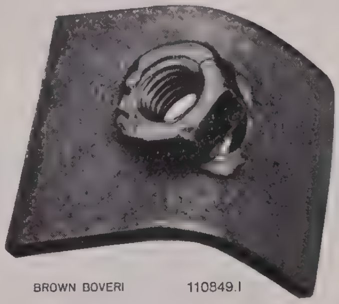
[2] Trade name for products of Messrs. Bauer & Schaurte, Neuss, Germany, to whom we are indebted for permission to publish Fig. 17b, c, 18 and 19.

Spot welding brass to steel is accompanied by a number of fundamental difficulties because, on the one hand brass and steel do not alloy very well and, on the other, their specific resistances differ appreciably from one another. The outcome of this is that, from experience, brass requires roughly twice as much current as steel. When spot welding with normal rod-type electrodes it is to be expected that a considerable amount of spattering and swelling occurs on the steel side, and this has to be removed afterwards. Moreover the strength of the joint tends to vary considerably when the size, shape and state of the contact surfaces of the electrodes do not remain constant, or are not what they ought to be.

Such problems are encountered in the construction of rotors of electrical machines, for instance, where spacer bars or brackets have to be attached to the ends of stacks of laminations (Fig. 21) to produce ventilation passages. With single-spot welding it was possible to reduce the weight of the material of the former rivetted design by about 25% and the working time by about 30% but, for the reasons stated above, the joints always had to be cleaned and finished afterwards. When projection welding was introduced this extra and costly work was com-



a



b

c

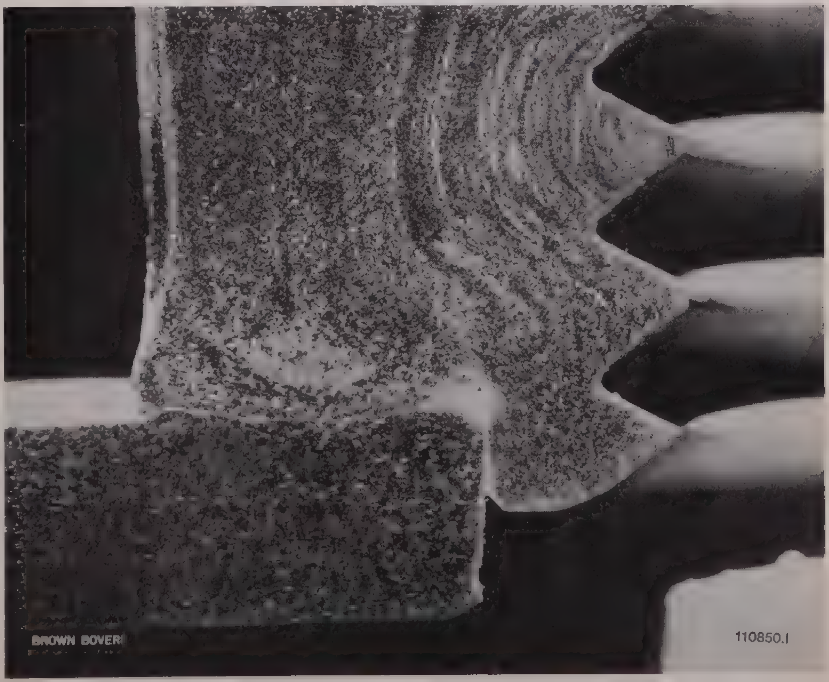
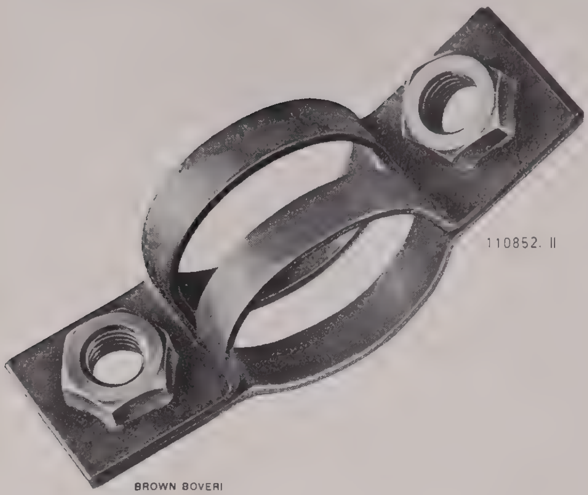


Fig. 17. – Projection welding nut

a: Cross-section. The cylindrical neck centres the nut in the hole, while the recess at the top protects the thread from damage by compression. Three projections round the skirt of the nut form a perfect three-point seating and compel the current to flow through the outer part of the skirt. As a result of this and the very short weld times which can be employed, the thread remains free from distortion and damage.

b: The peel test shows that the weld complies with the requirements.

c: Macrograph of a section through a "Verbus" welding nut.



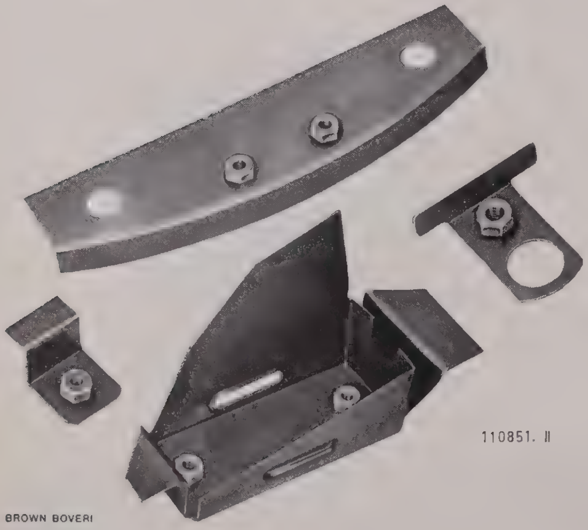


Fig. 18. – Examples of the use of welding nuts

Projection welding nuts are invaluable to the designer. They can be fitted in positions which are otherwise accessible with difficulty, and they involve no finishing work.

pletely eliminated, besides reducing the time by about 50% compared with single-spot welding. Finally, not only are the welds extremely clean, they also attain higher and more uniform strength values.

An instructive example from the construction of electrical apparatus is illustrated by Fig. 22. The task of joining the core and yoke of relay coils, for instance, where rivets or screws were formerly used, can now be performed much quicker. Using a Brown Boveri projection welding installation it is possible to weld up to 350 such assemblies per hour, without any spatter. That relatively thin sheet metal parts which have to stand vertical can be reliably welded to their counterparts is illustrated by the interesting examples shown in Fig. 23 and 24.

The advantages accruing from projection welding, irrespective of whether the weld is executed on a strong spot welding machine with a vertically moved upper electrode, or on a high-powered projection welding unit, are the same from the technical aspect. The choice of machine is governed solely by the opportunities existing for its employment, the utili-

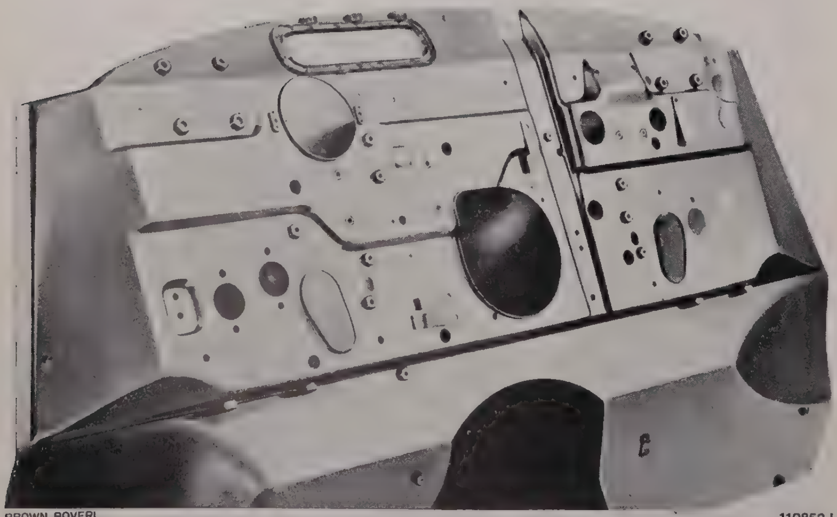


Fig. 19. – Example from the automobile industry

The advantages of using projection welding nuts are clearly illustrated.

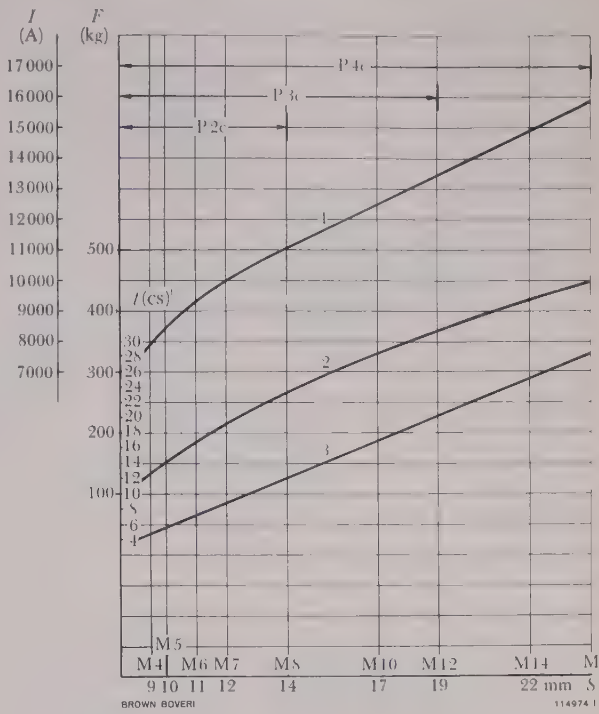


Fig. 20. – Settings for welding "Verbus" nuts

(Results of tests performed by Bauer & Schaurte, Neuss, Germany, and Brown Boveri, in collaboration)

These approximate figures apply when using Brown Boveri pneumatically operated spot welding machines types P2c, P3c, P4c.

The current setting corresponding to the particular throat area (arm projection times vertical distance between secondary conductors) is obtainable from the data sheet included with the operating instructions for the particular machine.

M = Metric nut size (thread)
S = Size across flats
1 = Welding current I in A
2 = Electrode force F in kg
3 = Weld time t in 0·01 s

zation factor, the stipulations regarding the power supply, as well as the visualized increase in output and the economics. When expediently planned and correctly applied, projection welding offers the following advantages.

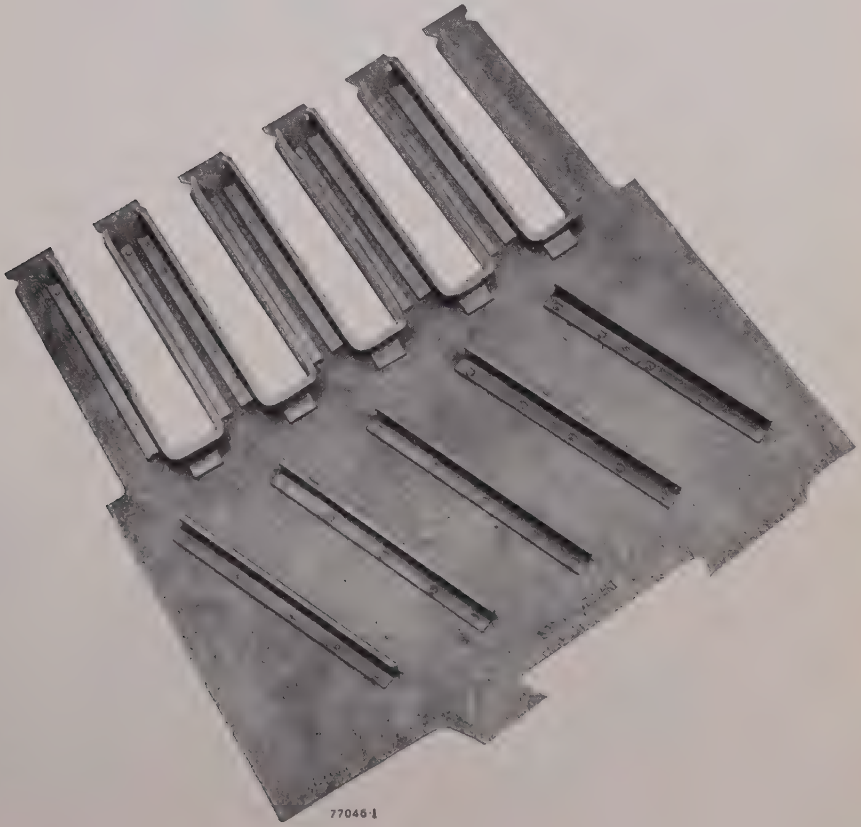

77046·1

Fig. 21. – Projection welding used in the construction of stators or rotors of electrical machines

By employing projection welding, spacers of steel or brass can be rapidly and neatly joined to segments of electrical sheet. The resultant saving in time is quite appreciable. In addition, better and more uniform strength values are attained; expensive trimming is eliminated.

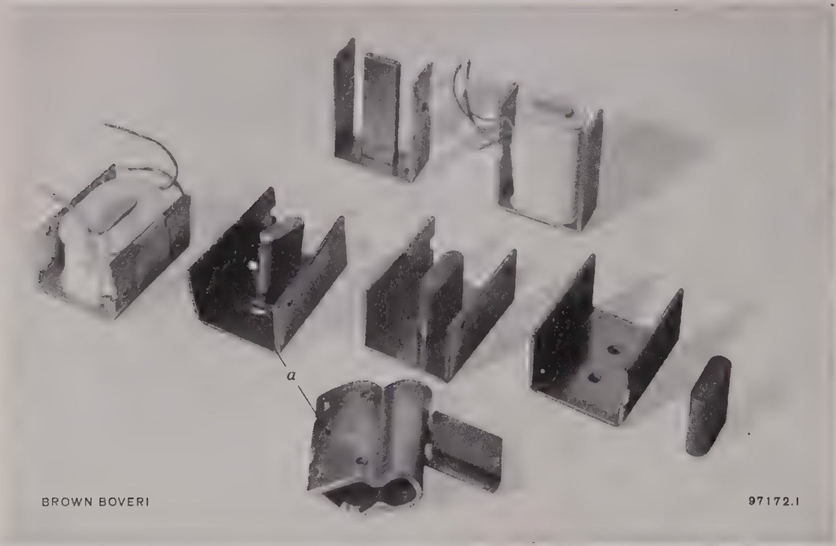


Fig. 22. – Projection welded solenoid cores

Instead of using rivets or screws, the core and yoke can be joined together by projection welding. This is quicker, cheaper and produces no spatter. The two peel tests are proof of the high quality of the joints.

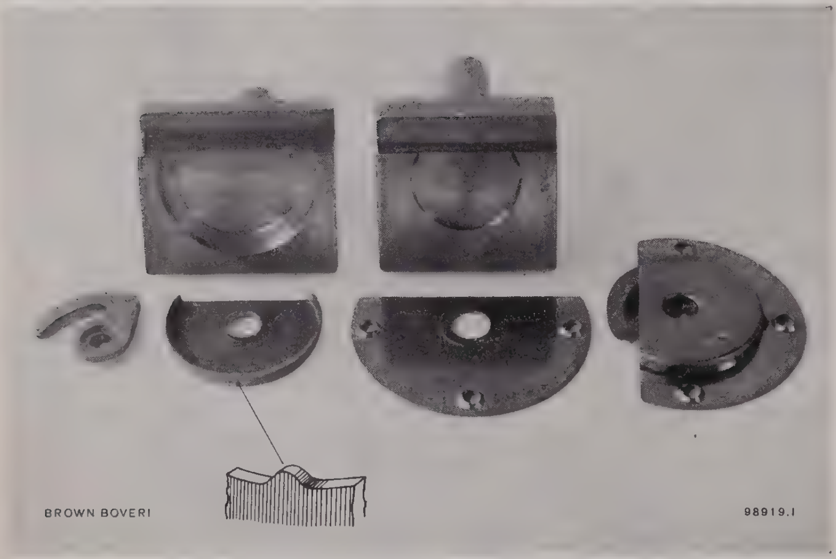


Fig. 23. – Projection welded lock case

Pressed parts of this kind can be satisfactorily joined with the aid of three small stamped lugs, half-round projections, in this case. This would not be possible with spot welding. The workpiece is centered by the actual electrode, which has a locating bar and is recessed to take the cover of the case.

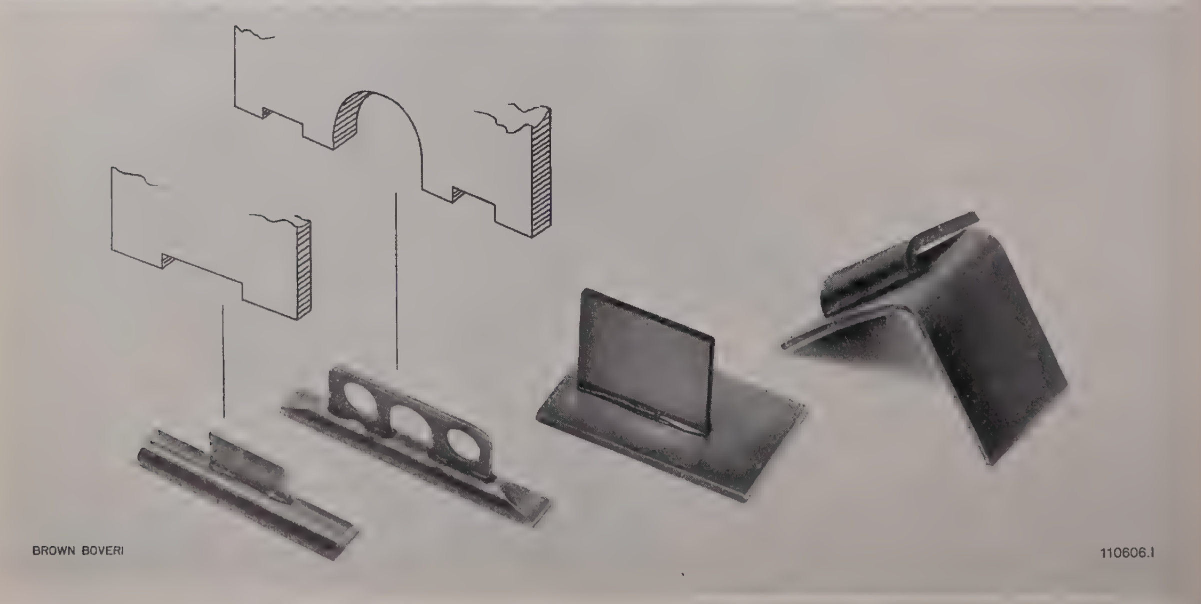


Fig. 24. – Welding thin vertical pieces on a horizontal base

By employing an electrode with self-locking clamps it is possible to join quite thin parts to the base. For the parts on the left the upper piece had two or four stamped feet. For the parts on the right the current was conducted by the smooth cut surface. For such tasks pulsation welding has proved ideal. The tests indicate the strength of the weld.

Increased output at lower production costs, since several spots can be welded in one stroke.

Improved dimensional accuracy and better appearance of the welded article, hence greatly reduced cost of surface treatment, especially when difficult paint finishes have to be applied.

More uniform welds and strengths, due to the absence of the shunt effect; also reduced heating of the workpiece, therefore practically no distortion needing expensive straightening out afterwards.

Prolonged life of the electrodes or their inserts, due to the reduced specific pressure and current and excellent facilities for cooling the tools.

Projection welding units with electro-mechanical, pneumatic or hydraulic auxiliary equipment are ideal for incorporation in production lines.

As a result of the suitability for mass or batch production processes and the excellent economics of projection welding, it is to be expected that this modern form of resistance welding will become increasingly popular in the future.

(KME) K. SCHÄRRER

Bibliography

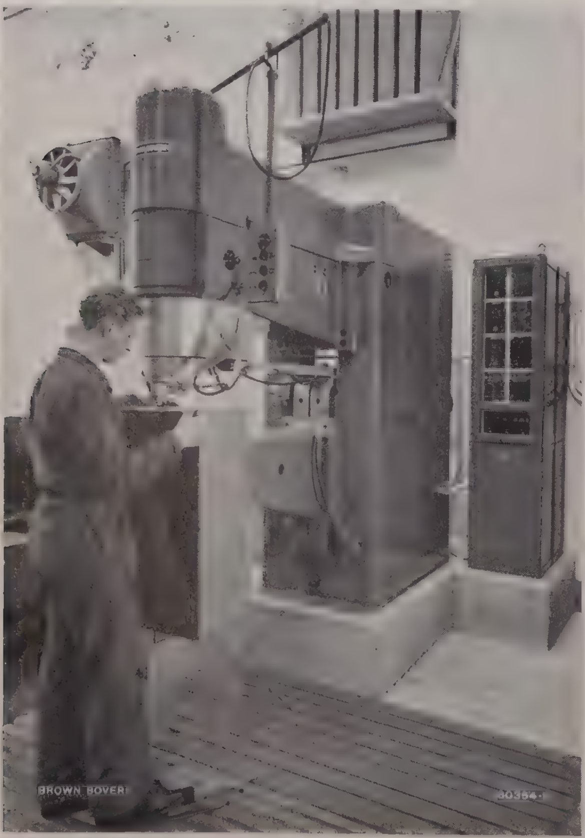
[1] W. BRUNST: Das elektrische Widerstandsschweissen. Springer-Verlag, Berlin 1952, p. 233–52.

[2] International Institute of Welding, Sub-Committee III (Resistance welding). Publ. III-103-58.

RESISTANCE WELDING MACHINES WITH THREE-PHASE FREQUENCY-CHANGERS

621.791.76.03:621.3.025.3

For resistance welding, especially spot and projection welding, machines having either long arms or arms wide apart, and connected single-phase, require a very high electrical input at a poor power factor. In the majority of cases the reactive power required to improve the power factor is produced by capacitors, usually connected in series with the load. Resistance welding machines equipped with a three-phase frequency-changer greatly reduce the intake of reactive power from the supply mains by lowering the welding frequency. On account of the special wave-form of the welding current and the low secondary frequency, and the correspondingly reduced secondary impedance, this machine is ideally suited to spot welding of light-metal and heavy-gauge sheet-steel, where very heavy currents are required.



Supply Problems

THE SHORT-TIME nature of the load inherent in the principle of resistance welding machines, and their relatively high power requirements, repeatedly raise the problem of the mains connection. Certainly most small and medium resistance welding machines can be connected to the existing, well-developed power supply mains, without exceeding the permissible voltage drop in the lighting network concerned—up to 2% for spot and 0·5% for seam welding. But cases are continually being encountered in which the welding power bears an unfavourable relationship to the short-circuit capacity available at the point of installation, and where there is no prospect of the power system being reinforced, at least at present.

The voltage drop in the system, caused by welding at maximum power, is the generally recognized factor for judging whether a welding machine can be connected or not. In most cases it does not make very much difference whether the load is three-phase or single-phase. If the system is powerful enough, and the voltage drop caused by welding does not exceed the limits stated above, it is quite permissible for a fairly large machine to be connected single-phase. Naturally in machines with long arm extensions, or those used for welding light-metals, the

Fig. 1. – Combined seam and spot welding machine for single-phase supply

The capacitor bank for power factor correction is mounted on the wall above the rear of the machine, thus occupying no floor space. The only effect on the control circuit is to make it necessary to use a different type of ignitrons.

poor power factor must be improved by appropriate measures. The most suitable method has proved to be the use of capacitors in series with the welding transformer, especially for machines equipped with electronic controls. This method is nearly always adopted, even for large spot and seam welding machines. The capacitor bank can usually be installed close to the machine, and does not occupy extra space nor does it require any attention (Fig. 1). Series power factor capacitors, however, necessitate the provision of a transformer exactly designed for the relevant conditions. When selecting the capacitor bank, standardized voltages are chosen, in order to take advantage of the lower price. It must be borne in mind that the capacitors and the transformer can only deliver the optimum power at a definite throat depth and a definite clearance. If these conditions, or the welded material are changed, the optimum power factor is no longer attained.

In spite of the ease with which a single-phase machine can be controlled, a system had to be found, the primary feature of which was to reduce the reactive power input from the mains as far as possible. If at the same time this system also reduces the voltage drop and balances the load on the mains by distributing it evenly between the three phases instead of only two, the more complex control system required for three-phase supply is obviously worth while.

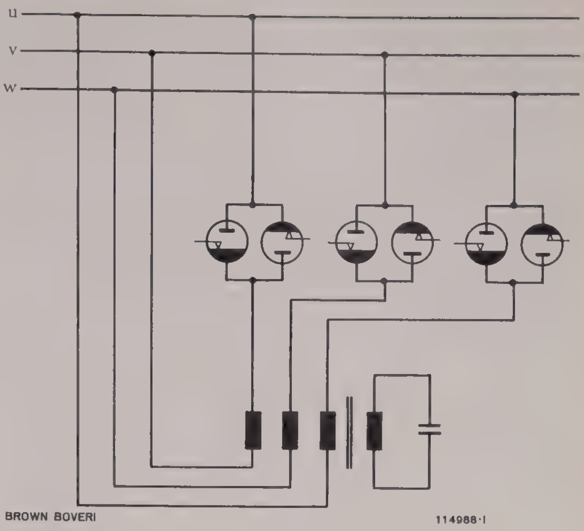


Fig. 2. – Schematic circuit diagram of a three-phase resistance welding machine with frequency-changer

A transformer with three primaries and one secondary is controlled by six ignitrons. All the windings are on the same core. In series with each primary is an antiparallel connected pair of ignitrons. Each winding and its pair of ignitrons is connected across a different pair of supply phases.

The three-phase/single-phase frequency conversion (Fig. 2) is effected with the assistance of a three-phase rectifier which reverses its polarity in the rhythm of a lower welding frequency. The rectifier is supplied by a single-phase transformer designed for the lowest frequency. Owing to the secondary frequency being reduced to, say $^1/_{10}$ of the mains frequency, the reactance of the secondary circuit

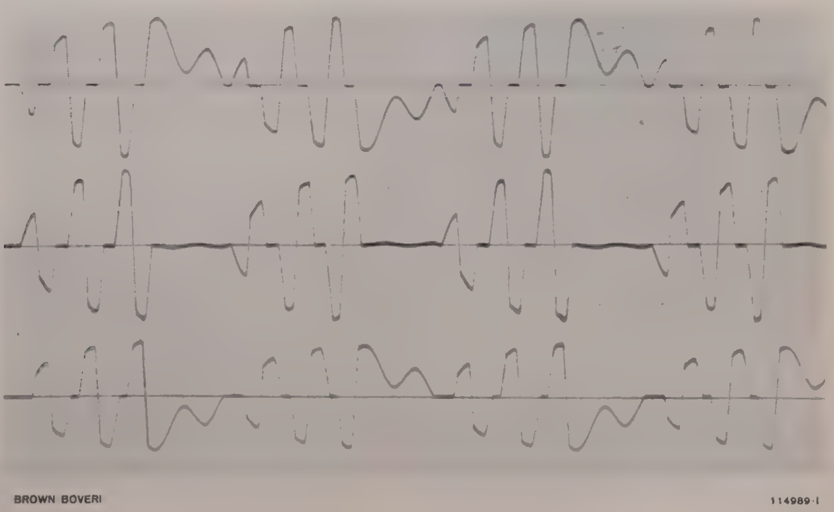


Fig. 3. – Oscillogram of the mains currents of a three-phase resistance welding machine with frequency-changer

Apart from the overlap times, there are never more than two phases conducting simultaneously.

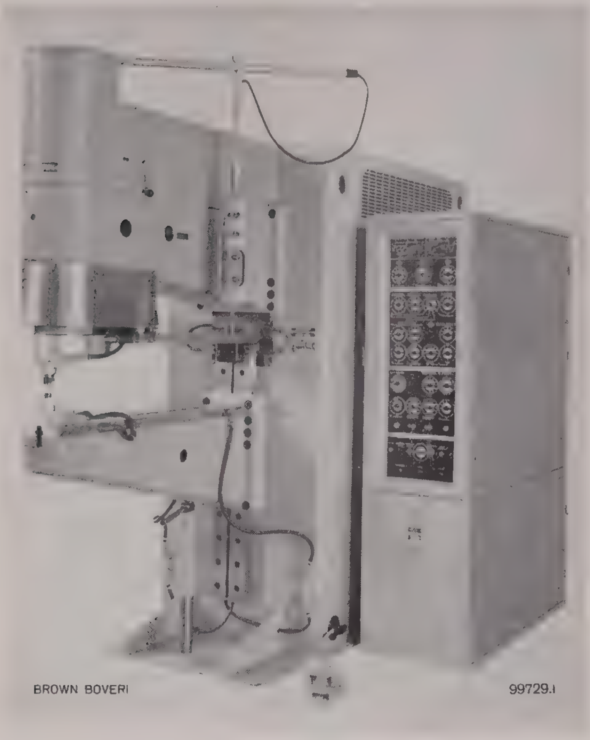


Fig. 4. – Three-phase frequency-changer resistance welding machine developing an electrode force of 1000 kg, with its electronic control unit

The steady increase in the powers stipulated for spot welding machines is responsible for the development of three-phase installations. The load is symmetrically distributed between the three phases. The electronic control system for a machine of this kind is considerably more complex than for a single-phase machine and demands a certain knowledge of the installation by the operator, who receives the necessary instructions during commissioning.

only produces $^1/_{10}$ of the reactive power at 50 c/s. The circuits are also symmetrical to within a few per cent. The only remaining point is that, with the frequency-changer system, each phase carries zero current for one-third of each cycle (Fig. 3). This produces a second harmonic, visible in the harmonic analysis of the mains current, the amplitude of which may amount to 20% of that of the fundamental. This phenomenon can generally be ignored because the power losses in the mains transformers and generators resulting from this second harmonic are usually of very brief duration.

The displacement factor ($\cos \varphi$) of the fundamental 50-c/s wave is a measure of the quality of the three-phase machine; values up to 0·9 are attained. When it has a high power factor, a machine with definite active power requires a lower reactive input and therefore causes less voltage drop in the mains. Hence in many cases it is possible to supply a three-phase machine having a still higher active power rating. Fig. 4 depicts a high-power three-phase welding machine with its electronic control unit.

Welding Properties

The welding properties of a machine with a three-phase frequency-changer are in most cases better than those of a single-phase machine with power factor correction. Owing to the considerable reduction in the inductive reactance of the welding circuit—lower frequency and reduction of the ohmic resistance of the secondary circuit on account of the reduced "skin" effect—the contact resistance and the ohmic resistance of the material assume greater importance. Therefore the current adjusts itself in accordance with the conductivity of the material being welded, i.e. it is high for good conductors and low for poor ones, which is exactly what is desired. Owing to the reduction in the inductance of the secondary

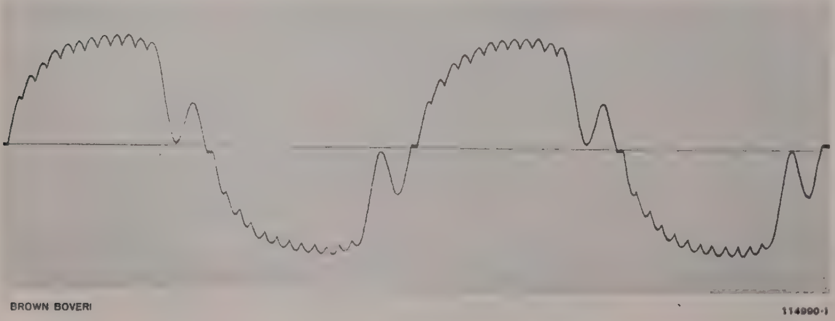


Fig. 5. – Oscillogram of the secondary current of a three-phase machine with frequency-changer

Apart from the 150-c/s ripple, the curve follows an exponential curve. The final transient, which can also be observed in the curve of the mains current, is due to stored magnetic energy, part of which flows back into the mains through the last ignitron to fire.

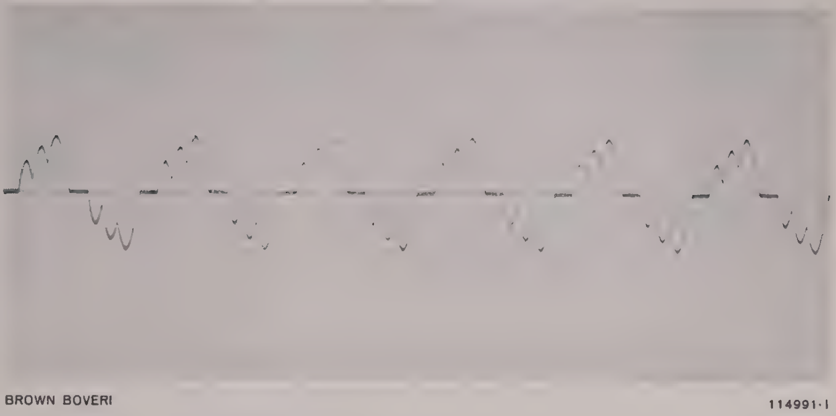


Fig. 6. – Oscillogram of the welding current with minimum pulse duration equivalent to maximum possible secondary frequency ($16^2/_3$ c/s)

The amplitude of the current can attain only a fraction of the value with longer pulse duration.

circuit, the magnetic losses resulting from the introduction of magnetic metal into the throat formed by the heavy-current conductors of the machine also decrease. The special wave-form of the welding current (Fig. 5) of the three-phase machine and, resulting from the low frequency, the ability to apply single half-waves of relatively long duration, renders this system ideal for spot welding light metals and their alloys. One half-wave of the low-frequency current is equivalent to several cycles of the mains-frequency current. The thermal effect on the spot welds is often better than with an ordinary single-phase machine where, in the same period, the current oscillates several times between zero and maximum. With the three-phase low-frequency machine the risk of the workpiece and the electrode alloying is greatly reduced. Another useful property of the three-phase machine is the extension of the range in which the current can be varied with long weld times. At each current setting, which is usually

Fig. 7. – Series of spot welds on light-metal

Absolute uniformity of the spots and absence of alloying are demanded of the welding machine.

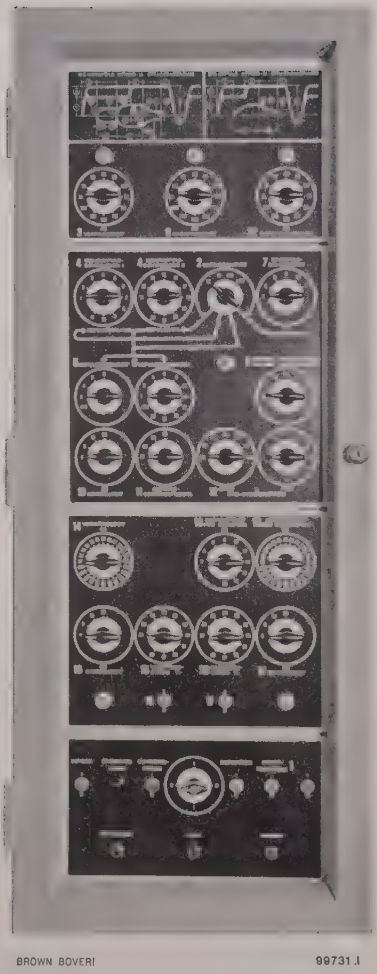


Fig. 8. – Panel of an electronic programme control for a three-phase welding machine with frequency-changer

With all the elements needed for setting the current, the times for welding and application of current, and for selection of the various programmes.

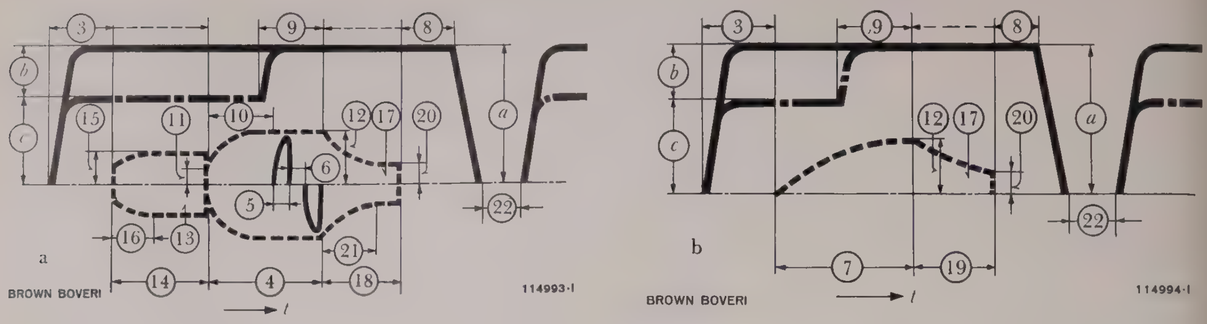


Fig. 9. – Pressure and current diagrams from the control unit of a three-phase machine with frequency-changer

a: For pulsation welding b: For single-spot welding

By omitting one or more of the indicated functions, programmes are obtained which have proved ideal in practice for spot welding the various alloys of steel and aluminium.

a = Forging pressure
b = Back pressure
c = Weld pressure
t = Time
3 = Squeeze time
4 = Weld time
5 = Heat time
6 = Cool time

7 = Single-spot weld time
8 = Forge time
9 = Delayed forge time
10 = Slope control for preheating
11 = Initial welding current
12 = Final welding current
13 = Pre-heating
14 = Preheat time

15 = Preheat current
16 = Modulation time
17 = Post-heating
18 = Post-heat time (a)
19 = Post-heat time (b)
20 = Post-heat current
21 = Drop-out time
22 = Off time

controlled by varying the firing point of the ignitrons, an additional control effect can be obtained by varying the current programme, i.e. the secondary frequency, and this effect can be combined with the first. As may be seen from Fig. 5 and 6, at higher frequency the welding current has a lower amplitude and therefore a lower r.m.s. value than at lower frequency. Consequently a three-phase machine intended for light metals can also be employed for mild or stainless steel which require far less current, without any connections having to be changed. Fig. 7 shows spot welds executed on a piece of light-metal, for which the power intake from the mains was 30% less with a three-phase machine than it was with a single-phase unit with power factor correction.

With three-phase machines pressure and current programmes adapted to individual conditions produce better spot welds, the advantages being particularly pronounced with light-metals and alloy steels. The extra outlay needed to realize such programmes is relatively small and certainly worth while in all cases where welds of high quality have to be executed. Fig. 8 shows the control panel of a three-phase electronic control unit. The large number of different programmes required to reliably weld various metals were taken into account in the design of the electronic control unit. Comprehensive instructions and tables of settings simplify the manipulation of the complex control system and enable appropriate programmes to be set up rapidly. Fig. 9 gives examples of the pressure and current programmes of three-phase machine with frequency-changer, and shows the different alternatives which can be obtained.

Thus when choosing a resistance welding machine the following points must be taken into account:

Generally speaking, the initial outlay is lowest with a single-phase machine. A stipulation regarding their connection, however, is that the supply system must be sufficiently powerful. If this is not the case, it is necessary to investigate whether the reactive load can be reduced by improving the power factor or by reinforcing the power system to such an extent that single-phase connection becomes permissible. The apparent inputs of three resistance welding machines having the same productive capacity and welding the same material, are in the ratio 2·5 : 1 : 0·7 when the first is a single-phase uncorrected machine, the second a single-phase machine with its power factor corrected to 0·8, and the third a three-phase machine with a frequency-changer. These comparative figures give some idea of the effect on the supply and the cost of the power.

Three-phase machines with frequency-changer allow light-metal to be welded by the single-pulse process, thereby reducing the risk of the electrodes alloying with the material being welded.

Before purchasing a resistance welding machine, it is advisable to decide what work is likely to be carried out, with particular regard to the size of the articles, qualities of materials, etc.; then which type of machine and control will prove most rational, and whether facilities exist for connection of that machine. Frequently the purchase of a machine proves that certain modifications to the design and production can offer considerable advantages. When all factors are properly checked, it is nearly always possible for the customer, aided by the welding specialist, to select the most suitable machine for his purpose.

(KME)

F. GERSPACHER
O. WALDVOGEL

BRIEF BUT INTERESTING

A New Design of Pantograph Current Collector for Express Electric Trains

621.336.322

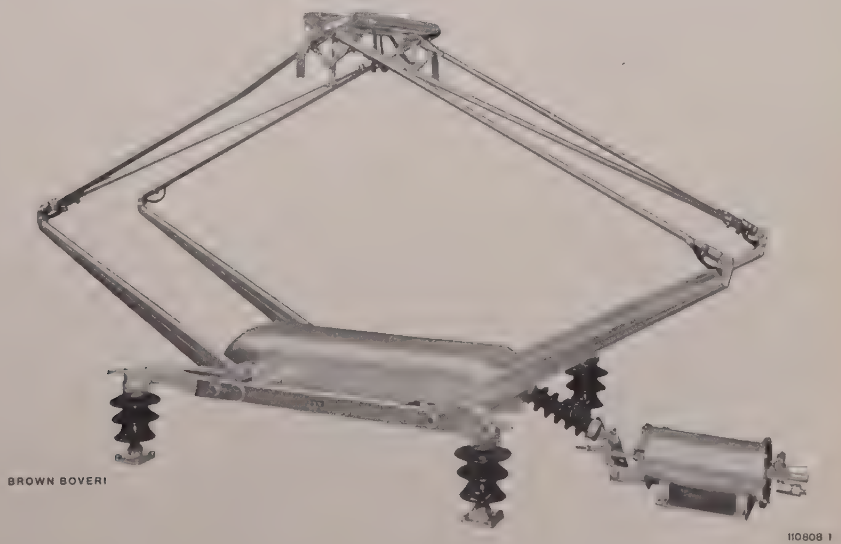
The construction of Trans Europ Express trains designed to run on different supply systems indicated the desirability of developing the current collectors accordingly. On the basis of the well-tried Brown Boveri design, a number of modifications and improvements were made, resulting in a collector which, to judge by the results of exhaustive tests in a wind tunnel and at high speed on actual trains, may be employed in the future not only on TEE trains, but generally for electric trains.

The pantograph mechanism makes allowance for the lowest and highest conductor wire systems in Europe. The pressure of the slipper strip on the conductor wire can be regulated by adjustable springs. The cradle, which is single or double according to the load current, is made to match the main load limit gauges both in shape and width, and can be changed in a few minutes. It is sprung vertically and lengthwise, and its contact pressure increases slightly with rising speed. As a result of the special design of the arms, it is possible to mount two collectors in a compact arrangement over one bogie.

The new collector has given excellent results in comparative high-speed tests carried out by the Swiss Federal Railways.

(KME)

A. GRASSET

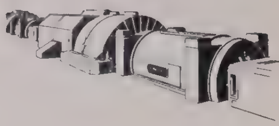


Current collector for Trans Europ Express trains

with single cradle 132 cm wide, slipper strip of aluminium, contact pressure 7 kg.

BROWN BOVERI PRODUCTS

POWER GENERATION



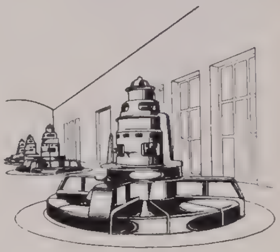
Steam and gas turbines for public and industrial power supply plants.

Velox boilers and accessories.

Boiler-house auxiliaries.

Generators for propulsion by gas, steam, or water turbines, or by diesel, petrol, or gas engines.

Generator protecting and regulating equipment: Protective relays. Electric heads for water-turbine governors. Electric governors for turbines. Automatic high-speed synchronizers. Quick-acting regulators: Voltage, current, current-limiting, power, power-factor, and frequency regulators; load-frequency controllers.



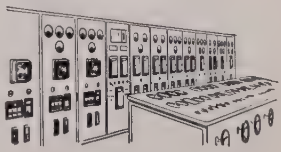
Emergency sets for maintaining lighting and ventilation during power supply failures.

Complete steam power stations.

Complete gas-turbine installations, stationary and mobile.

Machines and apparatus for atomic power stations.

Complete electrical equipment for hydro-electric and diesel power stations for automatic or semi-automatic operation; also with remote control.



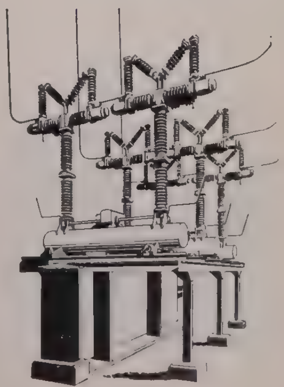
Switchgear for power stations of all types. Control rooms, if necessary with luminous diagrams. Remote supervisory control equipment.

POWER DISTRIBUTION

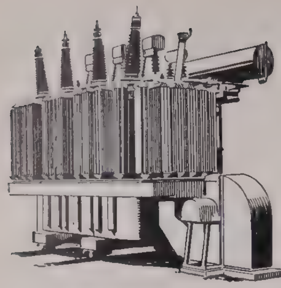
Substations for hand or remote control, semi- or fully-automatic.

Control desks and switchboards.

High-voltage switchgear: Oil circuit-breakers. Airblast circuit-breakers with or without high-speed reclosure. Convector-type circuit-breakers. Magnetic circuit-breakers. On-load isolating switches. H.V. single-column isolating switches. Metalclad draw-out switchgear.



Electrical-system protection equipment: Arc suppression coils. Lightning arresters. High-rupturing-capacity fuses. Relays of all kinds: Primary time-lag, primary thermal, secondary over-current time-lag, differential, inrush-proof ratio differential (for transformers), directional, frequency, earth-fault, minimum-impedance, high-speed distance, inverse-time overcurrent and time-lag relays. Relay test sets. Small contactors.

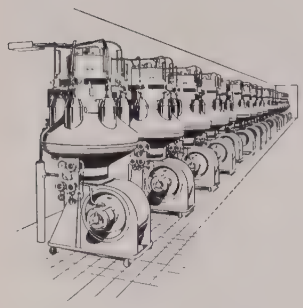


Transformers: Small and large transformers with and without voltage regulation. Induction regulators. Regulating transformers for low-voltage distribution systems. Current and voltage transformers.

Synchronous capacitors and phase advancers for voltage regulation and power-factor correction.

Mutators: Mutators for a.c.-d.c., d.c.-a.c., a.c.-a.c. (frequency changing) conversion. Pumpless mutators.

Rotating converters: Motor-generators.

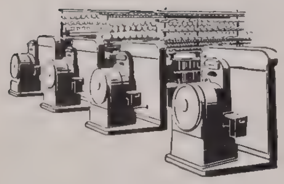


Contact rectifiers for electrolysis plants with heavy currents and low voltages.

Semiconductor rectifiers.

Charging equipment for batteries of all types.

POWER UTILIZATION

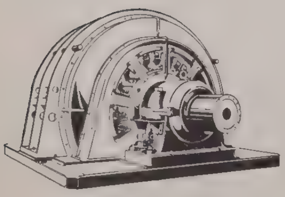


Complete electrical equipment for industrial plants.

Electrical equipment for textile, paper, cement, sugar, rubber, and other industries, for mining and metallurgical applications, pumping stations, conveying installations, printing works, machine tools, hoisting appliances, rolling mills, compressors, and fans.

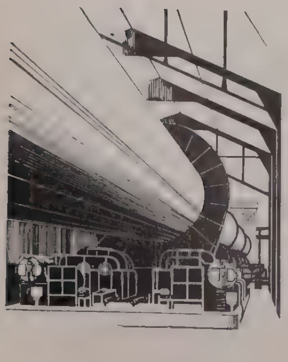
Variable-speed drives for all requirements.

Electronically controlled drives.



Motors of all sizes and types: A.C. induction, d.c., three-phase commutator, synchronous, synchronous-induction, geared, stop, twinstop and hollow-shaft motors.

High- and low-voltage industrial switchgear: Motor protecting switches and contactors. Circuit-breakers. Starting and control gear for hand and remote operation or automatic service. Enclosed low-voltage switch and distribution gear. Draw-out switchgear. Luminous diagrams for control, signalling, and supervision of widely ramified industrial installations.

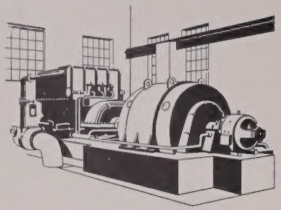


Electrochemistry: Galvanizing plants. Mutators and converters for aluminium electrolysis. Contact rectifiers.

Electric furnaces and kilns. For the ceramics industry: Chamber, truck, and tunnel kilns. For all metal winning and working processes: Ore-reduction furnaces, arc and medium-frequency induction-type melting furnaces for steel and grey cast iron. Mains frequency melting furnaces for grey iron and non-ferrous metals. Annealing and hardening furnaces. Foundry drying stoves. Electric crematoria.

High- and low-voltage electric boilers.

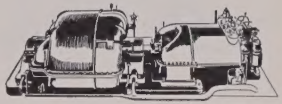
Electric welding. ARC WELDING: D.C. welding sets, welding rectifiers, multi-operator installations, welding transformers, automatic and semi-automatic arc welders. Argon welding equipment. RESISTANCE WELDING: Spot, seam, projection and butt welders. Timers. Energy regulators. Synchronous switches. Electronic controls.



TURBO-COMPRESSORS AND BLOWERS

Turbo-compressors with multi-stage intercooling for the production of compressed air for pneumatic tools and for the chemical industry.

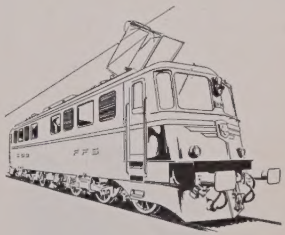
Blowers of axial-flow and centrifugal types for ore-reducing processes, for handling gases in coke-oven plants, for the chemical industry, and for pneumatic conveyors and evaporation plants.



Steam and gas turbines for driving blast-furnace and steel-works blowers.

Electric motors and gearing for driving compressors and blowers of all makes.

Heat pumps (Frigiblocs) for refrigerating applications in chemical works and air-conditioning plants in general and in mines.



TRANSPORT

Traction:

Electrical equipment for locomotives and motor-coaches (16⅔ and 50 c/s and d.c.), adhesion and rack railways, Diesel-electric locomotives and motor-coaches, and modern tram-cars and trolleybuses. Funiculars and aerial rope-ways. Individual-axle drives. Anti-slip brakes for locomotives, motor-coaches and tramcars. Motor-driven compressors. Control gear. Current collectors. Train lighting and heating equipment. Lighting turbo-sets for steam locomotives. Battery and contact-wire locomotives for industrial applications. Exhaust-gas turbochargers for locomotive and motor-coach diesel engines.

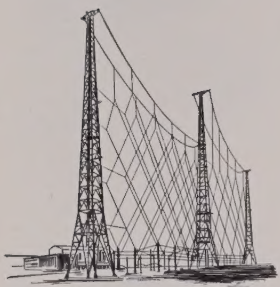
Marine propulsion machinery and auxiliaries:

Geared steam turbines and gas turbines for propeller propulsion. Velox marine boilers. Turbo-, diesel-, and gas-turbine-electric drives for ships of all kinds. Complete electrical equipment for submarines. Marine gears. Turbo-driven auxiliaries and electrical equipment for installation on ships, floating docks, etc. Turbo-dynamos for lighting installations and auxiliary power stations. Helux ship's lighting plants. Scavenging blowers for marine i.c. engines. Exhaust-gas turbochargers for marine diesel engines (main and auxiliary). Marine radio equipment (shore stations).

Aeronautics and aerodynamics:

Super- and sub-sonic wind tunnels for aerodynamic investigations. Hight-altitude test plants for reciprocating and jet aero engines. Dynamometers. Radio transmitting equipment for airfields.

HIGH-FREQUENCY, RADIO AND POWER SYSTEM COMMUNICATIONS



Transmitting and rectifier tubes.

Radio equipment for stationary and mobile service.

Radio relay equipment.

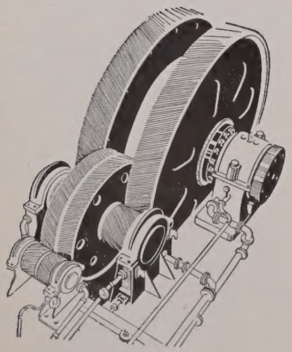
Transmitters for radio telegraphy, sound broadcasting, and television.

Carrier equipment for telemetering and control over power lines.

Electronic generators for industrial applications.

Thyralux units for smooth control of luminous intensity of neon and fluorescent tubes and incandescent lamps.

DIVERSE OTHER PRODUCTS



Gearing.

Gear couplings for all powers.

Hydraulic brakes.

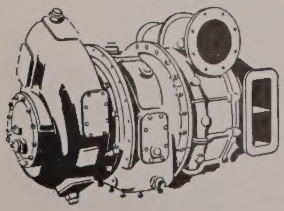
Electric dynamometers.

Electrohydraulic thrustors.

High-capacity air and oil coolers.

Raw-water evaporators.

Exhaust-gas turbochargers for increasing the power of two- and four-stroke diesel engines.



Laboratory equipment: Testing installations. Dynamometers. Frequency changers.

Particle accelerators.

Betatrons for materials testing and physical research. Asklepitrons for medical purposes.

BROWN
BOVERI

Published by Brown, Boveri & Company, Limited, Baden, Switzerland. Printed by Kreis & Co. AG., Basle, Switzerland
Obtainable direct from the publishers